CONTRACT NAS9-9953 MSC 02476
DRL NO: MSC T-575, LINE ITEM 73

SD 71-222

MODULAR space station
PHASE B EXTENSION

INTEGRATED GROUND OPERATIONS

PREPARED BY PROGRAM ENGINEERING
7 DECEMBER 1971

Space Division
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TECHNICAL REPORT INDEX/ABSTRACT

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MODULAR SPACE STATION INTEGRATED GROUND OPERATIONS

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ABSTRACT

THIS DOCUMENT FULFILLS A REQUIREMENT TO PROVIDE AN INTEGRATED APPROACH TO GROUND OPERATIONS. THE DOCUMENT CONTAINS INDIVIDUAL SECTIONS DESCRIBING REQUIREMENTS FOR DEVELOPMENT TEST, MANUFACTURING, FACILITIES, GSE, TRAINING, LOGISTICS SUPPORT AND LAUNCH OPERATIONS.

THE PRIME INTEGRATING REQUIREMENT IS THE EARLY ESTABLISHMENT OF A COMMON DATA BASE AND ITS USE THROUGHOUT THE DESIGN, DEVELOPMENT AND OPERATIONAL LIFE OF THE STATION. THE COMMON DATA BASE IS DEFINED, AND THE CONCEPT OF ITS USE IS PRESENTED.

DEVELOPMENT REQUIREMENTS FOR THE STATION MODULES AND SUBSYSTEMS ARE PRESENTED ALONG WITH PLANS FOR THEIR SATISFACTION. A MASTER DEVELOPMENT PHASING CHART IS PRESENTED ALONG WITH LOGIS FLOWS OF TEST ARTICLE UTILIZATION. MANUFACTURING, GSE, FACILITIES AND LOGISTICS SUPPORT REQUIREMENTS ARE GIVEN. LAUNCH OPERATIONS IN SUPPORT OF THE INITIAL STATION ARE PRESENTED.

FOREWORD

This document is one of a series required by Contract NAS9-9953, Exhibit C, Statement of Work for Phase B Extension-Modular Space Station Program Definition. It has been prepared by the Space Division, North American Rockwell Corporation, and is submitted to the National Aeronautics and Space Administration's Manned Spacecraft Center, Houston, Texas, in accordance with the requirements of Data Requirements List (DRL) MSC-T-575, Line Item 73.

Total documentation products of the extension period are listed in the following chart in categories that indicate their purpose and relationship to the program.

ADMINISTRATIVE REPORTS	TECHNICAL REPORTS		STUDY PROGRAMMATIC REPORTS	DOCUMENTATION FOR PHASES C AND D	
				SPECIFICATIONS	PLANNING DATA
EXTENSION PERIOD STUDY PLAN DRL-62 DRD MA-207T SD 71-201	MSS PRELIMINARY SYSTEM DESIGN DRL-68 DRD SE-371T SD 71-217	MSS DRAWINGS DRL-67 DRD SE-370T SD 71-216	EXTENSION PERIOD EXECUTIVE SUMMARY DRL-65 DRD MA-012 SD 71-214	MSS PRELIMINARY PERFORMANCE SPECIFICATIONS DRL-66 DRD SE-369T SD 71-215	MSS PROGRAM MASTER PLAN DRL-76 DRD MA-209T SD 71-225
QUARTERLY PROGRESS REPORTS DRL-64 DRD MA-208T SD 71-213, -235, -576	MSS MASS PROPERTIES DRL-69 DRD SE-372T SD 71-218, -219	MSS MOCKUP REVIEW AND EVALUATION DRL-70 DRD SE-373T SD 71-220			MSS PROGRAM COST AND SCHEDULE ESTIMATES DRL-77 DRD MA-013(REV. A) SD 71-226
FINANCIAL MANAGEMENT REPORTS DRL-63 DRD MF-004	MSS INTEGRATED GROUND OPERATIONS DRL-73 DRD SE-376T SD 71-222	MSS KSC LAUNCH SITE SUPPORT DEFINITION DRL-61 DRD AL-005T SD 71-211			MSS PROGRAM OPERATIONS PLAN DRL-74 DRD SE-377T SD 71-223
	MSS SHUTTLE INTERFACE REQUIREMENTS DRL-71 DRD SE-374T SD 71-221	INFORMATION MANAGEMENT ADVANCED DEVELOPMENT DRL-72 DRD SE-375T SD 72-11			
	MSS SAFETY ANALYSIS DRL-75 DRD SA-032T SD 71-224				

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PURPOSE AND SCOPE

The purpose of this document is to provide a tool to assist in planning an integrated approach to all aspects of ground operations. Ground operations is defined as those activities required for development, manufacture, qualification, acceptance, launch, and refurbishment of all MSS modules. It includes the effects of the activities on ground support equipment, facilities, training, and logistics support.

In the past, documents associated with the various facets of ground operations were written so each would be essentially self sufficient. This not only leads to a large amount of redundancy of test procedures and descriptive data, but imposes a disproportionate amount of work to keep all documents to the same reference. The Integrated Ground Operations document defines each document and its interrelationship to the other documents so that, by proper referencing, the most recent data will always be utilized in all areas.

The common denominator of ground operations (and orbital operations) is the common data base which will permit the maximum use of all data generated during the life of a subsystem and assess and predict its performance. Through the Integrated Ground Operations document, guidelines have been established to coordinate the planning of data requirements, and data handling (manipulation, compaction, storage, etc.) and to implement the common data base in all areas of ground operations.

Each section is written to cover a particular area of ground operations in such a fashion that it can be separated from this document during later program phases if the need arises.

1. GUIDELINES AND DEFINITIONS

1.1 PURPOSE

This section of the Integrated Ground Operations document provides a set of ground rules or goals that will be used in the development of the various areas of ground operations, defines the principal documents concerned with ground operations and shows their interrelationship so that redundancy will be minimized, and establishes the requirements and utilization concept for a common data base for program operations.

1.2 SCOPE

The guidelines are written to include ground operations from development tests through manufacturing, qualification, and acceptance; GSE, training, facilities, maintenance, and logistics support; and launch and refurbishment. These guidelines were used as a means of coordinating the various disciplines and related documents comprising the integrated ground operations. The various documents contributing to integrated ground operations were prepared to a consistent level of detail reflecting the proper relationship and dependency to other documents.

1.3 GUIDELINES

The guidelines were established to provide the basis for development of integrated ground operations. These guidelines were used as a starting point and as direction indicators for each section of the Integrated Ground Operations document. The guidelines are listed in the following paragraphs.

1.3.1 COST AVOIDANCE

Commonality of structural components, subsystem components, and handling equipment for each of the Space Station Program modules will be a design goal.

Commonality goals will include ground service and checkout equipment as well as flight hardware.

Elimination of environmental testing (acoustics, vibration, thermal vacuum) of a fully configured module is a program goal.

Qualification requirements will be identified for all Space Station Program hardware. These requirements will be compared with projected development and acceptance tests for equivalence to assure that tests will not be duplicated.

Subsystems assemblies, subassemblies, components, and GSE will be identical to those developed for space shuttle to the maximum extent possible.

Space Station Program hardware acceptance specifications will be established before initiation of procurement activities and will define the acceptance criteria explicitly.

1.3.2 TEST

Commonality of test procedures for each subsystem element, subsystem, and integrated subsystems will be a design goal.

Computer routines developed for checkout of individual assemblies will be complete within themselves and capable of being incorporated into combined or integrated programs without reformatting.

Combined tests of those modules required to accomplish the basic station functions, i.e., multiple berthing, power generation, and subsystem control, will be conducted prior to launch of the initial module.

Development Test

Verification of all development requirements resulting from new designs must be satisfied by analysis or development tests, or a combination of both.

The establishment of a common data base and the determination and verification of checkout and operational procedures will be a requirement of the subsystems development program.

Maintenance approaches and procedures will be developed and verified on the subsystems development programs.

Structural testing will verify a satisfactory design margin for operational limits.

Primary structures, structural interfaces, and functional interfaces between modules will be statically and dynamically verified by test, analysis, or a combination thereof.

Software developed and supplied with subsystems hardware will be integrated and verified as being compatible prior to start of combined subsystem tests.

Life tests on subassemblies and components will be based primarily on the expected life of the assembly in which the hardware is installed. The test duration will be modified by the following: (1) whether the hardware is an in-flight replaceable unit (IFRU) or ground replaceable unit (GRU), (2) the criticality of the function performed by the hardware, (3) the number of spares carried aboard the station, and (4) resupply cycles of the shuttle. Life tests of common subassemblies and components will be based on the most stringent set of requirements.

All subsystem development testing will include a teardown and inspection phase to the extent practical. The degree of teardown and inspection will be individually defined for each subsystem.

Qualification

A qualification matrix will be developed to identify all tests and analyses contributing to the qualification process and to define specific additional tests or analyses requirements to complete qualification of the space station subsystems.

A launch confidence assurance matrix will provide the control and management visibility to assure timely accomplishment of the program test requirements.

Tests at the subsystem level will be for the purpose of verifying interfaces and interactions with other subsystems and with the information subsystem/onboard checkout (ISS/OBCO) at the functional limits and in normal operation, including alternate and redundant modes.

Acceptance

Space station hardware acceptance specifications which define the acceptable criteria explicitly will be established before initiation of procurement and manufacture of flight hardware.

An acceptance specification tree will standardize test documentation and assure compatibility of requirements (including performance requirements and tolerances) at each level of acceptance from subsystem elements to a complete module.

The maximum feasible use will be made of NASA-developed universal test equipment (UTE).

Components

Acceptance tests at the component/subassembly level will include flight-level environments plus a margin to assure that the accepted item will perform its required function in the operational environment at its anticipated extremes.

Subsystems

Acceptance testing at the subsystem level (installed in program modules) will include a demonstration of alternate/redundant modes of operation, together with the malfunction switching logic, by exercise of subroutines inherent to the onboard checkout capability.

Wherever possible, alternate/redundant path checkout capability, via malfunction simulation, will be an inherent subsystem checkout feature and will be accomplished without disturbing the flight configuration.

In the event of malfunctions, combined systems tests will continue with the exercise of planned maintenance modes to return the configuration to operating status and continuance of the combined system process.

Subsystem elements and their software instruction package (top language instruction related to software requirements) will not be accepted by the prime contractor until verification of internal redundancy has been successfully demonstrated within the limitation of the vendor's ability to duplicate the operational interfaces.

Each subsystem test program will include subsystem acceptance tests before installation. Subsystem performance will be to the same operational ranges expected in orbit.

Electromagnetic compatibility (EMC) will be established at the design level and verified in the normal test and checkout sequence. Special EMC tests at the modular level will be avoided.

Modules

Elimination of vacuum testing of a complete module (space station core module, common module, etc.) will be a program goal.

The onboard checkout capability will be used as a basis of acceptance testing for the space station end items.

At the system level, all alternate/redundant modes of operation must be successfully demonstrated to verify all functional space station interfaces and to assure that the onboard checkout capability will adequately status all modes of operation by means of appropriate subroutines.

Acceptance of the various modules for launch will be accomplished by a combination of tests utilizing a test tool that will verify all subsystem primary and redundant paths applicable to the particular module.

An integrated test tool will be utilized to evaluate returned modules for required rework and to accept reworked modules as ready for relaunch.

Operational Test

For each subsystem inflight replaceable unit (IFRU) initially installed to the space station or replaced in flight, there will be a capability for verifying functions and associated interfaces before the IFRU goes on line.

All new or modified subsystems hardware supplied via the resupply system will have OBCO test programs (subroutines) developed, qualified, and supplied with the new equipment.

The onboard checkout capability will be used as the basis for operational checkout of the space station modules.

All physical and functional interfaces between space station modules will be verified by test and analysis or combinations thereof.

Experiments Test

All experiment modules will undergo acceptance testing at the supplier's facility before shipment.

All experiments programmed for inclusion in the general-purpose laboratory module launches will be installed at the manufacturing facility before the module acceptance test.

Experiments included in the initial launches of the station modules and which have a functional/dynamic interface with the station command, control, or statusing functions will have a prototype hardware installed in the integration test tool for functional checkout and compatibility verification prior to installation in the space station module.

All experiments hardware scheduled for launch with a station module must be accompanied by the appropriate checkout and operational software instruction package at each delivery point.

Before delivery for installation in the shuttle, experiment modules programmed for subsequent shuttle delivery during the operational life of the station will be interfaced with an integration test tool for functional checkout and compatibility verification only (no sensor operation) and for software/ISS verification.

All modules will be packaged for launch in such a way that no additional support is required after installation in the shuttle orbiter.

1.3.3 MANUFACTURING

Commonality of parts, assemblies, and tooling will be given maximum consideration in the manufacturing flow.

Producibility analysis will be performed on all of the manufacturing processes.

Maximum use of the current manufacturing technologies will be utilized for the manufacturing processes.

Multiple use will be made of test articles, i.e., they will be used as a manufacturing development fixture as well as a test article.

Acceptance tests of subsystems assemblies will utilize the central data bank as a source for comparison data and will augment the data bank with acceptance test data.

Modules will be checked out individually using an integration test tool that will check out and verify all redundant paths within the module and those with which the module is involved.

Major test articles will be constructed of assemblies commensurate with the primary objectives of the test. For instance, structural test articles will be constructed to flight-type specifications and drawings, and thermal test articles will be constructed to the same processes (for thermal control) as flight assemblies. Test articles will be built to the same specifications, but not necessarily fabricated with the same tooling as flight articles.

Station modules will be transported from manufacturing/acceptance site to the launch site in an operable but quiescent or inactive mode.

The onboard checkout capability will be used as the basis of acceptance for the space station modules.

1.3.4 GSE

Checkout and acceptance of individual modules will employ simulation devices to represent the functionally interfacing modules.

Wherever possible, GSE used for subsystems acceptance will be relocated (if required) and utilized in module (or next assembly) acceptance.

Parameters used for modular level acceptance tests will be common to those used for operational data and malfunction evaluation.

Utilization of general-purpose GSE will be a goal; special-purpose GSE will be kept to a minimum.

Demonstration of the interface between the modules and facilities by use of a dimensional simulator will not be required.

Maximum commonality of GSE with the space station will be a goal and the maximum feasible use will be made of NASA-developed UTE.

1.3.5 FACILITIES

Modification to facilities in support of the MSS program will be minimized.

Any new facilities will be of the general-purpose type wherever possible to facilitate use on future programs.

Existing facilities and transportation systems will be recommended for use wherever possible.

Use of program hardware simulators for facility checkout will be permitted only where required to avoid excess handling or potential damage to program hardware.

Wherever possible, the same facilities will be utilized for final assembly, checkout, and testing of the MSS program hardware.

When environmental contamination control is required during assembly of components, this same environmental control will be maintained wherever these components are exposed during the assembly and testing processes.

1.3.6 FLIGHT CREW TRAINING

Crew Definitions

Operations Crew: personnel responsible for station operations, management, and maintenance (commander, flight controller, and systems engineer).

Support Technicians: experiment and station support electronics, mechanical, biology, or medical skills personnel.

Experiments Personnel: individuals responsible for the conduct of experiments such as the medical doctor, biologist, agriculturist, etc.

Guidelines

The flight crew should monitor, or have the option to participate in, tests and checkout of individual modules or combinations of modules.

Unique or periodic dynamic operations such as shuttle berthing, attitude changes, and orbital makeup should be practiced by the flight crew in dynamic simulators.

Provisions will be incorporated in the development program for the flight crew to monitor and practice scheduled periodic and unscheduled maintenance procedures and techniques.

The scope of training for individuals (i. e., station operations, stations subsystems, RAM's operation) will be consistent with personnel assignment (reference crew description).

Command and control techniques unique to the modular space station (MSS) will be practiced using the ISS capability in conjunction with special input programs developed for crew training purposes.

Use of existing simulators and training aids will be considered. It is anticipated the crew training requirements will be of sufficient magnitude and frequency to require facilities and equipment dedicated to that purpose.

1.3.7 MAINTENANCE AND LOGISTICS SUPPORT

Resupply requirements will be determined using the inventory control feature of the common data base in conjunction with the onboard status capability of the ISS.

Maintainability procedures will be developed and verified on the subsystem development program.

Initial inventory of spares will be calculated from the maintainability analysis and life expectancy and criticality of the function of the IFRU's considering the expected life of the module in which the hardware is installed.

Consideration will be given to the problem of maintaining supplier capability over the projected life of the space station.

1.3.8 PRELAUNCH SERVICING AND REFURBISHMENT

Noncritical consumables will be loaded into modules prior to module installation in the shuttle.

Acceptance tests of refurbished modules will utilize the same module test points as originally used at the manufacturing/assembly location.

Hazardous servicing of modules will be performed while the module is installed as a payload in the shuttle at the shuttle launch pad.

Modules will be individually checked out using an integration tool to provide the intermodular functions.

Combined tests of those modules required to accomplish the basic station functions of multiple berthing, power generation, and subsystem control will be conducted prior to launch of the initial module.

The ISS onboard checkout capability will provide the primary prelaunch checkout functions.

1.4 DEFINITIONS

The following paragraphs describe the requirements for the common data base and propose a concept for its utilization as well as the content and relationships of the various ground operations documents.

1.4.1 COMMON DATA BASE

The changing character of oncoming space programs such as the shuttle, with its multiple reflights and two-week turnaround; and the space station, with its 10-year life, attendant resupply requirements, and extensive OBCO capability, implies a need for a more responsive technical data management system then those used on past programs which were oriented toward a single vehicle operation over a relatively short time span. This change in program character is expected to result in a substantial increase in the quantity of data generated as well as a demand for improved accessibility and faster response time. The MSS approach to resolution of the technical data management problems is the common data base.

The common data base consists of all program technical data indexed to a common format for ease of access and flexibility of presentation. The data base is contained in an automated fast access file system (computer memory) which has several basic functions such as the following examples:

1. A repository for design, test, and operational parameters
2. A working file for test procedures, tolerances, and results
3. Configuration management
4. Consumables, spares levels, and resupply requirements
5. Mission management and crew functions

In the broad sense, the common data base is considered as one of the integrators of the total ground operations for the MSS program. These activities include manufacturing, test, logistics support, personnel training, maintenance and repair, facilities, ground support equipment, and launch operations. The common data base, therefore, must accommodate subsystem performance specification requirements; development, design verification, qualification, and acceptance test data; manufacturing in-process verification data; launch operations, recovery, refurbishment, and relaunch data; orbital operations data; inventory control data; and onboard crew record summaries. (see Figure 1-1).

Requirements

Data must be recallable at any point in the program for use in evaluating anomalies and comparing subsystem performance. Real-time analysis of subsystem malfunctions will be accomplished by recalling data from the common data base. These data will determine subsystem performance immediately before the malfunction, as well as trend data as far back as possible.

The data base will have the capability to present data in various classes (exact classes to be determined during Phase C), including the following:

1. Short-term trend data in the form of time history plots of single or multiple parameters (pressure, temperature, voltage, amperage, flow, frequency, etc.)

2. Cross plots of selected parameters (pressure vs temperature, voltage vs amperage, etc.)

3. Calculated data which are derived by suitable equations acting on stored data (thrust, wobble, logistics requirements, etc.)

The onboard data base will continuously store all subsystems performance parameters for a predetermined number of hours. These data will be stored on a first-in, first-out (FIFO) basis, so that at the moment of anomaly, the preceding hours of data (in real time recording) can be recalled for analysis.

Data leaving the real-time storage will be compacted by the method specified for each parameter (Phase C determination), then sent to the archive memory storage for transmittal or transport to the ground for permanent storage in the main data base (see Figure 1-2).

All input data to the data base must have a compatible format. Computer routines, developed for checkout of individual assemblies, will be complete within themselves and capable of being incorporated into combined or integrated programs without reformatting. The actual format will be identified in the software system specification.

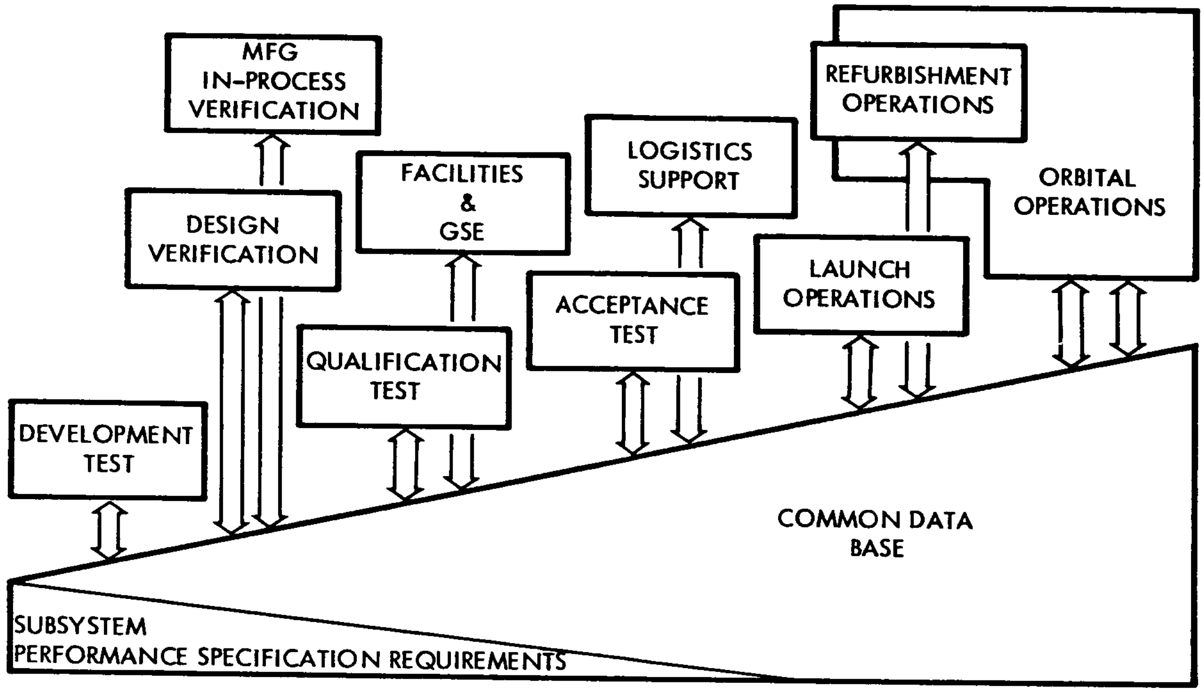


Figure 1-1. Common Data Base

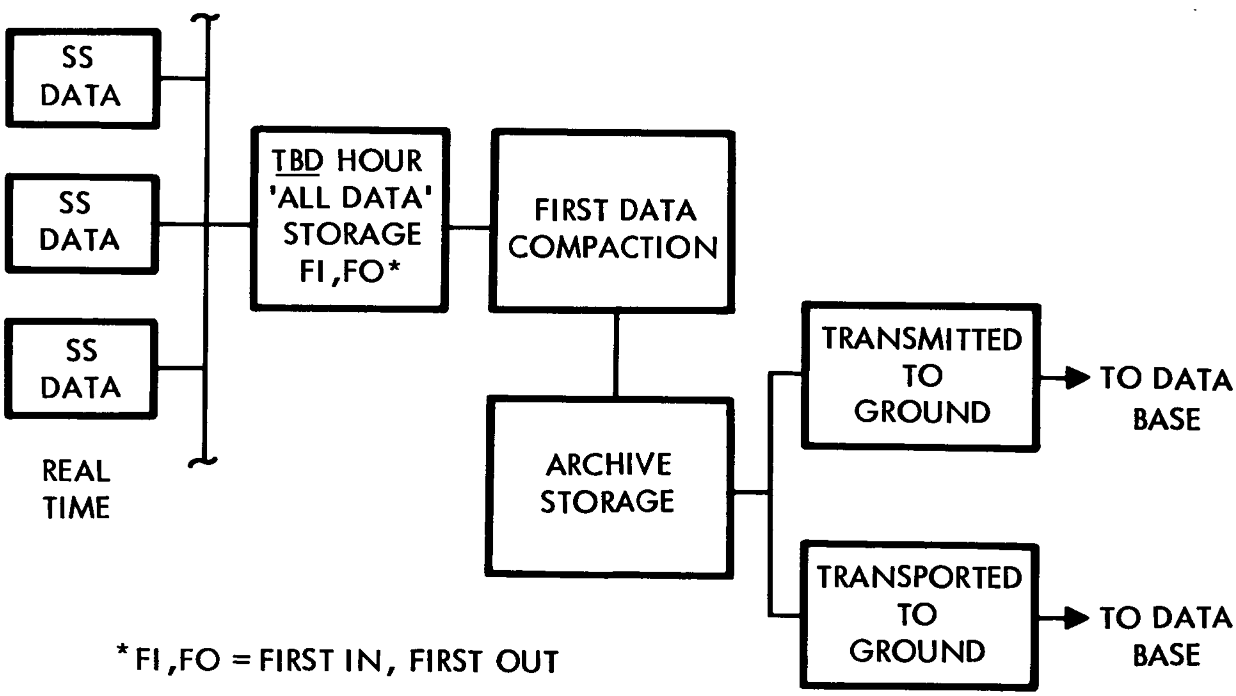


Figure 1-2. Data Flow to Ground

Utilization Concept

The common data base is conceived as a means to document all phases of the Space Station Program. To fulfill this task, the data base will be a repository for all space station subsystem performance data. Starting with subsystem design requirements, it will include subsystem specification values, test results from component, subassembly, assembly, and subsystem development tests, as well as subsystem qualification and acceptance tests.

Data from all module acceptance tests, combined tests, on-orbit verifications and operations, will also be stored. Figure 1-3 shows the sequence of accumulating the various levels of data depicted by this conceptual approach to the common data base.

The content of the data base will vary as the program matures. The initial operating data will be design values, part numbers, specification details, etc. As the development cycle progresses, the data base will be expanded to include component history (failure rates), configuration management (indentured parts lists), consumables inventory, current test procedures, test data, etc. Table 1-1 establishes the scope of the common data base by showing some of the anticipated functions, how they will be utilized, and the final useful products.

1.4.2 GROUND OPERATIONS DOCUMENTS

The following paragraphs describe the various major documents required for ground operations of the MSS program. In the past, these documents were written so each was self-sufficient, which led to redundancy of test procedures and descriptive material which in turn imposed a disproportionate amount of work to keep all documents to the same reference. By integrating all the documents described (Sections 2 through 8) into one ground operations document, the prime source of data for each operation is identified and the interrelationship of each document is established.

Development Test Plan (Section 2)

The Development Test Plan section of the integrated ground operations document identifies the development requirements for the modular space station by subsystem, their methods of resolution, hardware required, and their associated constraints. Concepts for the development and integration of the following are presented:

1. Subsystems development

2. Subsystems integration (physical and functional)

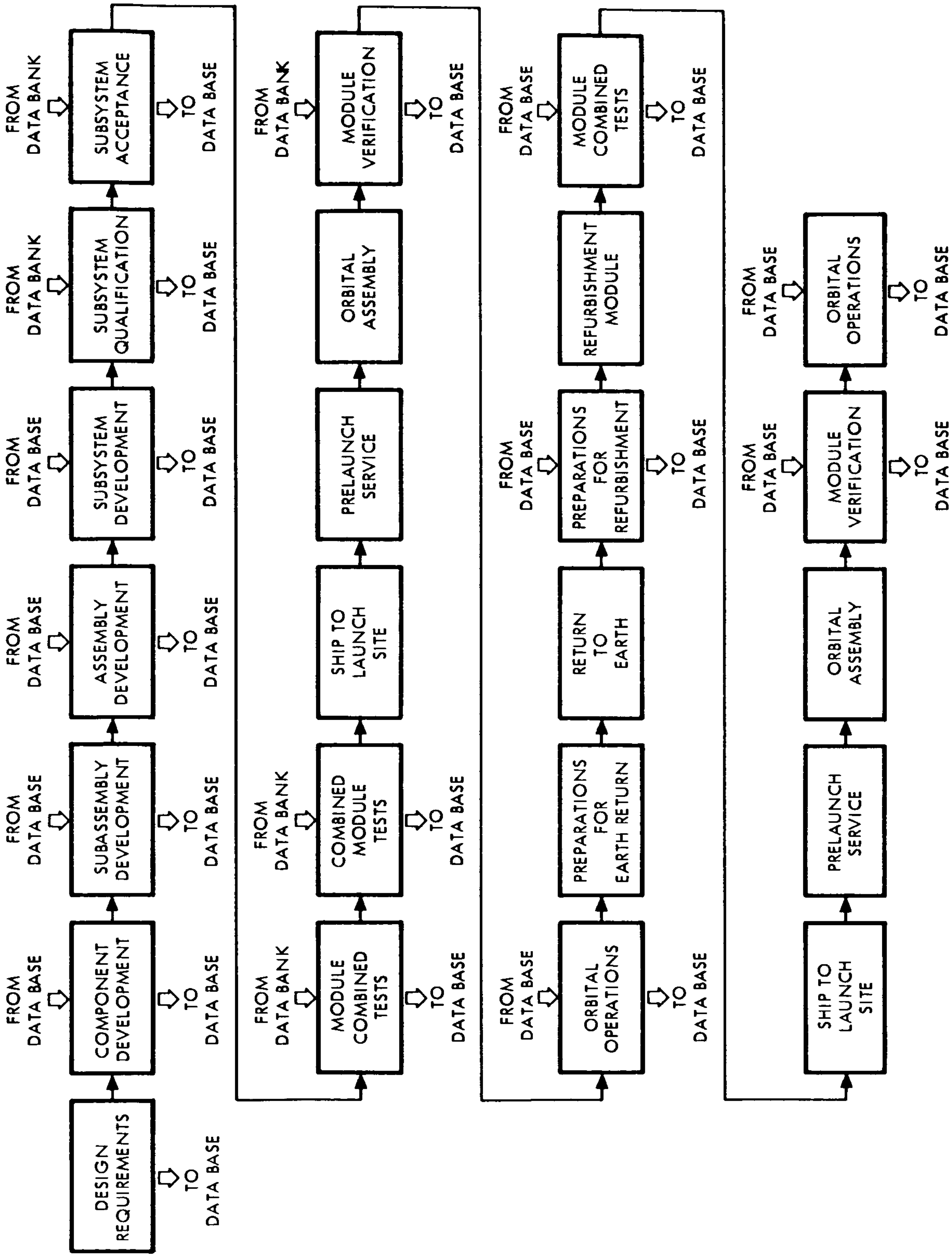


Figure 1-3. Accumulation of Data

Table 1-1. Data Bank Functions (Example)

Store	Operate	Display
Subsystem design parameters (test point values)	Update with test results and experience	Current values
Test procedures	Perform checkout	Results
Configuration management (part numbers)	Record remove and replace	Current configuration
Component history (failure rates)	Compare with projections	Spares requirements
Consumables inventory	Subtract usage Compute rates	Current levels and projected requirements
Qualification requirements (matrix)	Compare with test results	Qualification status
Test results	Successive comparison	Trend data
Component operating time	Update each "on" cycle	Total time on each component-time to go to failure predicted
Personnel data	Time on-orbit, tests taken, health status	Current status

3. Interface verification

4. Acceptance and qualification

5. Checkout and launch operations (initial and relaunch)

6. Recovery and refurbishment

The basis of the test requirements which result in the test plan is the Systems Requirements Book (SRB) (or specifications). Subsystem descriptions will be referenced to the SRB.

Test procedures prepared for development tests will be the basis (as much as possible) for acceptance, manufacturing verification, and prelaunch checkout. Therefore, the documentation required for these activities will have its origin in the test plan. These procedures will be stored in the common data base for universal usage.

Manufacturing Plan (Section 3)

The Manufacturing Plan applies the guidelines established in paragraph 1.3 of this section and presents an approach for the MSS modules manufacturing activities. These manufacturing operations include illustrations of top-level manufacturing sequences through checkout for all space station modules identified by the preliminary design. Brief descriptions of the following manufacturing activities are included:

1. Manufacturing engineering and development
2. Resources planning
3. Production control
4. Production planning
5. Special tooling and support equipment
6. Fabrication, assembly, and installation
7. In-process verification
8. Delivery
9. Common data base support to the manufacturing operation

The basis for test requirements for in-process verification is the Systems Requirements Book or model specification as interpreted by the test plan. The in-process verification will rely on and support the common data base by supplying procedures and comparative data.

Reference to facilities and GSE to support the manufacturing activities will be made in Sections 5 and 4, respectively.

Ground Support Equipment (Section 4)

This section defines the ground support equipment, to level 5, required to support the flight elements of the MSS consistent with the guidelines established in paragraph 1.3 and the level of the Phase B station definition.

Subsystem and module requirements for GSE will be based on the Systems Requirements Book or specification, as applicable.

Requirements for GSE to support manufacturing operations as well as subsystems installation, checkout, and maintenance are included.

Facilities (Section 5)

The major facility requirements for the MSS have been determined by performing trades and analyses at the site level where modular station requirements significantly differ from those of Station A.

These requirements are presented by narrative description and rationale for the development, manufacturing, and acceptance and delivery sites.

This document responds to the manufacturing, test, training, maintenance and logistics, and launch and refurbishment in defining facility requirements. These definitions are consistent with the development and checkout flows given in Sections 2 and 4 and the level of preliminary design defined during the Phase B study.

Training Plan (Section 6)

This section establishes the training philosophy, approach, and the flightcrew training requirements. Alternative methods of fulfilling training requirements are identified with the most operational and cost-effective (where known) training method recommended. In-flight maintenance training, orbital assembly, and disassembly training is emphasized in addition to station and experiment operations training for various crew tasks and skills. Simulators, trainers, and mockup alternatives related to a selected training approach are identified.

The training plan is designed to provide crews trained to conduct the tasks identified in DRL 68, Operations and Crew Analyses. It will interface with other ground operations documents as follows:

Section 2, Test Plan. Crew participation in the test and checkout of the CAV, MSV, and flight articles and their subsystems are defined.

Section 5, Facilities Plan. The functional requirements for the crew training site and the personnel and training equipment facilities utilized for training at that site are defined.

Section 7, Maintenance and Logistics Support. The support to training requirements determination from the logistics support operations analysis for station and mission support maintenance is defined.

Section 8, Launch Site Operations Plan. Station crew participation during prelaunch and launch operations for preparation of the station modules for launch is defined.

Maintenance and Logistics Support (Section 7)

This section defines the requirements and establishes a maintenance and logistics support system to conduct effective operation of the MSS program throughout the various phases of its life cycle.

The section covers the maintenance and logistics activities during the design development, test, and operational phases of the MSS program. The requirements, tasks, interfaces, and approach to implement the maintenance and logistics system are described.

A maintenance concept is defined which provides the baseline and criteria for maintenance requirements and planning, and the support resource requirements.

Also defined are the requirements for the individual functional elements of logistics, i.e., maintenance, maintainability, inventory management, documentation, test, and operational support.

A management approach is identified which provides the processes and techniques required to implement the functional elements described previously. This section includes the following:

1. Support requirements analysis
2. Maintainability analysis
3. Inventory management
4. Technical support documentation
5. Test support operations
6. Operational support

The maintenance and logistics support plan is in response to the requirements outlined in Section 2 of this document (Test) as well as the operational requirements defined in DRL 74, Modular Space Station Program Operations Plan.

Launch Site Operations (Section 8)

This section of the report includes the results of the analyses of the prelaunch and launch operations conducted for determining the requirements for the launch site. The results of the study established a minimum cost approach to the mode of operation through use of existing facilities and equipment, and provided recommendations for the incorporation of features into the space station elements that will utilize existing equipment rather than creating new requirements. (For greater detail, see SD 71-211, MSS KSC Launch Site Support Definition.)

Where pertinent, the baselines and other guides used for the study are included. Typical information is the shuttle model and interfaces, facilities, and operational concept. Time-phased flow plans for all representative elements of the Space Station Program have been established. Tests are identified for defining GSE and facility requirements. An assessment of the existing major facilities and equipment was conducted to determine KSC's capability to support the MSS operations.

2. DEVELOPMENT TEST PLAN

2.1 PURPOSE

The purpose of this section is to describe the development test plan for the Modular Space Station (MSS) program. This plan will establish the basic checkout philosophy and flow, identify requirements for the utilization of existing and new test facilities, and serve as a guide for preparation of detailed development plans for the individual subsystems and major test articles.

2.2 SCOPE

This section summarizes the ground rules applied to develop the MSS test plan, and describes the dependency on other testing programs. The subsystem development issues, as well as the resulting test requirements and test hardware, are described. The checkout sequence and checkout hardware requirements at the manufacturing and launch sites are described. The development program phasing chart and test facilities requirements are also included.

2.3 TEST PHILOSOPHY

The primary goal in all test activity is to acquire confidence that the equipment will perform its required functions in the mission environment in a satisfactory manner. Even in the early development testing to validate concepts or selected components, the final goal is confidence in mission performance. Because an objective way to measure confidence has not yet been devised, test requirements are usually developed subjectively. The tendency is to test a great deal more than is really necessary and to lose sight of the end objective. The test becomes a test for test's sake rather than a building block in the establishment of confidence. Recognition of the need for objective test evaluation has resulted in the creation of specialized test disciplines such as qualification, acceptance, and prelaunch checkout.

These test disciplines have evolved to the point that the need for them and their contribution to the overall confidence level is rarely questioned. For example, the approach to acceptance testing in most hardware programs has become one in which passing an acceptance test is the goal in itself. A malfunction detected at that point results in a test failure and normally a complete recycle with the attendant wear on the systems. A better approach would be to consider the acceptance test as another link in the confidence chain. When a malfunction occurs, success has been achieved since a weak point has been exposed. A further extrapolation of this philosophy is to make use of the detected malfunction to exercise and evaluate the associated maintenance routines, thus gaining confidence that the planned isolation, mission continuation, and repair procedures are adequate. In no case should the subsequent recycle go any further back than is necessary to re-establish the test configuration at the time of malfunction.

A key factor in being able to apply this philosophy to space station testing is a rigorous test planning activity prior to the start of the test program. Each test in the program must be planned and phased with data utilization in mind. Each planned test must be assessed for its contribution to the overall confidence goal.

Confidence goals must be realistic. That is, they must contain risk vs cost elements. A goal of 100 percent confidence, without consideration for cost or acceptable risk, will obviously lead to a very expensive test program. The key is to find the optimum relationship of cost vs risk (or confidence) and structure the test plan accordingly.

The assessment of risk, in terms of cost, requires a detailed knowledge of each test objective and its relationship to the total program. The level of detail that can be generated during a Phase B study does not lend itself to a comprehensive analysis of risk. However, a gross evaluation is possible and was used to keep the planned tests as effective as possible in establishing confidence in mission success.

2.4 GROUND RULE SUMMARY

The ground rules, as written for ground operations (see section 1), are designed to assure an integrated approach to test, manufacturing, ground support equipment, facilities, flight crew training, logistics support, and prelaunch operations. The use of the common data base as the prime factor for integrating the several ground operations activities is a basic requirement.

Cost avoidance was stressed by setting as a goal maximum commonality of structures between like modules, and commonality of subsystem assemblies, subassembly, GSE, etc. between the MSS and the shuttle to the maximum extent possible. Additional cost avoidance is accomplished by integration of development, qualification and acceptance testing, and orbital operations.

The ground rules for test stress the integration of requirements, procedures, and data for development, qualification, acceptance and launch operations, as well as the use of the onboard checkout capability (OBCO) for acceptance and checkout.

Manufacturing ground rules provide for its integration into the total ground operations by providing for the following:

1. Commonality of parts and processes to reduce tooling
2. Tying the production operations with other ground operations by use of the common data base.
3. Utilizing the OBCO capability to the maximum extent possible for in-process testing.

Ground support equipment and facilities ground rules provide for:

1. A goal of shuttle-station GSE commonality
2. Minimizing the requirements for special-purpose GSE
3. Utilization of existing facilities with a minimization of rework.

Ground rules for integrating crew training into the total ground operations suggest:

1. Crew participation in the checkout sequences
2. Use of the ISS capability to simulate operational situations
3. The need for dedicated training facilities to satisfy the 10-year continuing crew training requirement.

Maintenance and logistics support ground operations ground rules provide that:

1. The ISS and the common data base provide the basis for configuration management and resupply requirements, program spares, and consumable inventories controlled by ground computer facility
2. Development of maintenance procedures will be a requirement of the subsystems development programs.

Prelaunch and refurbishment ground rules state that:

1. Modules will be individually checked out using the integration tool to provide the intermodular functions
2. Combined tests of those modules required to accomplish the basic station functions of multiple berthing, power generation, and subsystem control will be conducted prior to launch of the initial module
3. The ISS OBCO capability will provide primary prelaunch checkout functions.

2.5 PREPROGRAM TESTING

The development program presented herein for the MSS is planned to utilize the preprogram testing presently under way or proposed. These include the environmental control space station prototype (SSP) test being conducted by Hamilton Standard, the information management development breadboard tests being studied and conducted by NR, and NASA continuing development programs being conducted at either MSC or MSFC. For convenience, these will be referred to as NCDP in this document.

The SSP tests will resolve several of the development issues identified for the ECLSS in paragraph 2.7. In addition, the hardware resulting from this development will be installed in the NCDP modules for the resolution of certain integrated development issues.

The information management advanced development tasks of the Phase B MSS program will result in hardware that will resolve in whole (or in part) some of the issues identified for this subsystem in paragraph 2.7. The hardware, i.e., breadboard data acquisition and control subassembly (DACS), consisting of the breadboard data bus control unit (DBCU), the breadboard digital data bus, and a Government-furnished remote acquisition and control unit will be used in connection with other subsystem breadboards and the NCDP modules to resolve many integrated development issues. These integrated issues concern the interface between the information subsystem (ISS) and other subsystems such as electrical power and environmental control/life support.

The NASA continuing development programs are planned to take full advantage of the technological resources and time available in the 1972-1974 period to resolve MSS development issues which can be resolved prior to Phase C and are considered key issues in the continuing development of a low-cost Space Station Program.

These programs will continue the early development testing accomplished in the individual disciplines of environmental control and information management by integrating the development hardware into representative modules for initial interface testing. If the NCDP do not materialize, alternative solutions must be planned to resolve the issues, depending on this preprogram testing.

2.6 DEVELOPMENT REQUIREMENTS

Development requirements for each of the MSS subsystems were determined by a systematic approach defined as development requirements analysis (DRA). By means of the DRA, development issues and their methods of resolution were identified for each subsystem. This section summarizes the methodology used as well as the development requirements established to level 6 (assembly) for each of the subsystems. These requirements must be expanded and iterated during later phases of the program.

2.6.1 DEVELOPMENT REQUIREMENTS ANALYSIS

The approach to the MSS test program is one in which the individual disciplines and skills associated with the traditional development, qualification, acceptance, and operational checkout phases of a test program are integrated into a single comprehensive program. Subsystem test requirements were determined by the systematic DRA. The subsystem, system, and element development issues were identified, analyzed, categorized, and synthesized into individual subsystem test programs, and integrated into the MSS test program.

Development issues are defined as anticipated problem areas identified and recognized from a detailed examination of the product usage (element, subsystem, etc.) and its special characteristics. They are identified by a thorough examination of the program elements and their subsystems against the following:

1. Functional requirements during prelaunch, ascent, and earth-orbit operations
2. Trade trees
3. Functional flow diagrams
4. Buildup concepts
5. Design concepts
6. Failure analysis
7. Crew tasks

Identified development issues are then analyzed by the application of the following steps:

1. Description and classification. Each issue is described and classified as one of technology, design/process, or operation.

2. Resolution. Primary and alternative methods of resolving the issue are defined, and the criteria for satisfactory resolution are specified.

3. Configuration. The test hardware and any interfacing subsystems required for the suggested resolution are specified.

4. Requirements. An identification is made of the key test parameters to be observed during the tests, prerequisites to the test being proposed, constraining events, and subsequent events that will be constrained by issue resolution.

5. Program impact. Program impact is assessed to determine the positive or negative effects of issue resolution on the program. This provides the basis for justification of the issue resolution.

6. Preliminary schedule. A preliminary schedule is developed based on the requirements and constraints identified in (4) above and the probable sequence of testing to be followed.

7. Collation of requirements. All DRA's are collated, and initial determination is made as to test requirements by subprograms (i.e., major test articles), test logic, hardware summaries, facility and GSE requirements, generic measurement requirements, etc.

8. Formulation of a near-optimum test program. A near-optimum test program is formulated by combining and phasing major test hardware.

The DRA results in documentation of all development issues identified, regardless of whether they appear to have already been satisfied (resolved), require only documentation, or demand extensive development.

Tables 2-6 through 2-14 (Section 2-11) list and describe the development issues identified to date for the various subsystems. Issues are at least to level 6, but in some cases are given to a lower level to provide a more comprehensive picture of the total development required. The tables indicate the various categories for the resolution process and their general hardware requirements.

2.6.2 TEST REQUIREMENTS

The resolution of the development issues has been grouped into sets requiring like kinds of resolution/test disciplines. These subprograms are summarized below and include the following resolution processes:

a. Analysis

b. Mockup

c. Zero g simulation

d. Engineering test laboratory

e. Static tests

f. Dynamic tests

g. Thermal-vacuum tests

h. Integration tests

i. Flight demonstration*

Detailed tabulations of the subprograms, describing the development issues, tasks, and the event supported or constrained, are given in Section 2.11, Tables 2-15 through 2-23.

Analysis

The initial step in resolving most development issues consists of an analysis, either mathematical or dimensional, to set design concepts. The analysis will be accomplished early in the Phase C and constrains various stages of drawing release of the several subsystems.

Table 2-15 (Section 2.11) lists the various issues requiring analysis, the tasks required, as well as the event being supported or constrained by the task.

Mockup

Soft mockups provide a cost-effective tool to partially resolve some development issues. Table 2-16 (Section 2.11) lists 14 basic development

*Aircraft, Skylab, Apollo, Shuttle, or MSS initial operations issues requiring mockup for resolution. These issues are primarily concerned with fit and function of the design, configuration of the modules, and the installed subsystems. The tasks shown in Table 2-16 will be accomplished early in Phase C to relieve the constraints identified.

Zero G Simulation

To determine the effects of weightlessness on the crew, and the ability of crewmen to perform their tasks, simulation of zero is required. Development issues identified for partial resolution by zero g simulation will utilize a six-degree-of-freedom simulator, KC-135 tests, or neutrally buoyant tests. Other issues require the utilization of air-levitated models for resolution. Table 2-17 (Section 2.11) defines the tasks to be accomplished by zero g simulation for resolution of the development issues listed.

Engineering Test Laboratory

The majority of development tests of the various subsystem components, subassemblies, and assemblies will be conducted in engineering test laboratories.

The tasks listed in Table 2-18 (Section 2.11) include those that must be conducted by the various subcontractors as well as the prime contractor in the development of the subsystems. The tasks listed are not all inclusive of the development work to be accomplished, but will be the basis for the subsystems development plans that will be prepared during Phase C. The relative timing of the test completion is indicated by the identification of the event being supported or constrained by each task.

Static Environment

Static tests of the MSS structure will be conducted by accomplishing the tasks listed in Table 2-19 (Section 2.11). These tasks will be the basis for preparing detailed test plans for the modules described in paragraph 2.6.3. The phasing will be as shown in paragraph 2.8 to support the events listed in Table 2-19.

Dynamic Environment

Dynamic tests of the three major modules (power module, core module, and station module) will be conducted to determine modal frequencies and response to dynamic and acoustic excitation. Shaker tests to determine dynamic modes, mode shapes, frequencies, damping characteristics, and internal loadings will be conducted. These tests are required for two general purposes: to assure the ability of the various subsystem components to withstand the boost environment and operate properly in earth orbit, and to obtain data for G&C design refinement.

The development issues to be resolved by the dynamic test program are listed in Table 2-20 (Section 2.11).

Thermal-Vacuum Environment

Thermal-vacuum testing is required to resolve some structural and mechanical subsystem development issues. These tests will be conducted on assemblies (a part of this program) and representative modules (a part of the NCDP). The advanced testing to be accomplished by NCDP will minimize the complexity of the thermal-vacuum test program. However, if this program does not materialize, further consideration must be given to the need for a representative TV test module.

Those development issues identified for thermal-vacuum testing are listed in Table 2-21 (Section 2.11).

Integration Testing

Integration testing will include multiple systems tests conducted during the NCDP, individual module development, combined module development, and module acceptance (both individual and combined). During the module development phase, an integration tool will be developed that will assist in the integration of the software required for space station checkout, acceptance, and operations.

Table 2-22 (Section 2.11) lists the development issues by subsystem that require integrated testing for partial resolution. The tasks identified will serve as the basis upon which to prepare detailed test plans and procedures.

Flight Demonstration

Certain development issues require either actual weightlessness or actual space environment (or both) for high-confidence resolution. Table 2-23 (Section 2.11) lists these development issues, along with the tasks and constraints lifted by each test.

2.6.3 DEVELOPMENT TEST HARDWARE AND OBJECTIVES

The accomplishment of the development test program for the modular space station will require the major test articles described in the paragraphs which follow. Multiple use of test articles is planned in order to reduce costs. The flow of test modules is shown in paragraph 2.9.

Structural Test Modules

Three modules are required to accomplish the requirements of the structural test program: power module, core module, and station module (type A or B).

Each of these modules will consist of a primary structure but no secondary structure. Thermal finishes, radiators, insulation, and subsystems are not included. A secondary structure must be available upon completion of these tests to allow installation of prototype subsystems in the respective modules which will then become the compatibility assessment vehicle.

Detailed objectives for the structural test modules are as follows for the core module (CM), station module (SM), and power module (PM):

1. Demonstrate the structural integrity of the module to sustain all loads imposed by the shuttle, i.e., boost, landing, emergency, etc. (S-3).*
2. Demonstrate the ability of the internal bulkheads to sustain the maximum ΔP possible (in both directions)(S-16)(except PM).
3. Demonstrate the structural integrity of the modules to withstand combined effects of boost environment (acoustic/vibration + Δt) (S-4).

Dynamic Test Modules

The dynamic test articles will consist of one each of the power module, core module, and station module.

The modules will be flight-weight construction with all primary structures and all secondary structures required to install floors and dummy equipment. All equipment over 50 pounds will be installed in the proper locations or properly ballasted dummies provided. Dummy equipment must simulate both mass and center-of-gravity location.

The selection of a type A or type B station module for the dynamic tests will depend on the final configuration of these modules.

* Letters and numbers refer to the development issues listed in tables in Section 2.11.

The following objectives will be the basis of the dynamic program and will be resolved for each of the unique modules as applicable:

E-8. Determine the dynamic energy levels at the ECLSS equipment and measure the (partial) ECLSS equipment response to the dynamic boost environment.

S-7. Determine the frequency response characteristics and modal shapes when the module is subjected to high and low frequency vibrations, especially in the longitudinal axis.

I-10. Determine the dynamic energy levels at the ISS equipment and measure the (partial) ISS equipment response to the dynamic boost environment.

G-11. Determine the dynamic energy levels at the G&C equipment and measure the (partial) G&C equipment response to the dynamic boost environment.

G-12. Verify the computer dynamic model and associated transfer functions for the individual modules and various combined module configurations.

P-11. Determine the dynamic energy levels at the EPS equipment in response to the dynamic boost environment.

Acoustic Test Modules

The orbiter vehicle to payload interface control document (SR 2.4.4 - 11187) estimates the boost phase acoustic level to peak at 141 db (250 to 500 Hz) but not to exceed 153 db. Designers are to assume a duration of 30 seconds for the given spectrum, starting at booster vehicle engine ignition. This estimate of acoustic intensity is sufficiently high to warrant investigation of transmissibility factors which could have a detrimental effect on the subsequent operation of MSS subsystems.

These modules are the same ones utilized for dynamic testing and therefore have both primary and secondary structures installed, and all equipment of 50 pounds or more simulated and properly installed.

The following acoustic test objectives are considered a part of the total dynamic environment test series:

S-2. Verify ability of the modules structure to withstand the effects of the boost acoustic environment.

S-6. Verify transmissibility/attenuation factors for each unique module when subjected to the predicted acoustic profile.

Compatibility Assessment Vehicle

The compatibility assessment vehicle (CAV)(Figure 2-1) will consist of the following modules: a power module, core module, and station modules 1, 3, and 4. These modules will be flight-weight structures with prototype subsystems installed. The control stations are installed in station modules 1 and 4. Figure 2-3, (paragraph 2-8) shows the sequence for checkout and activation of the CAV. Basically, the power module and core module will be individually checked out and then combined. Station module 3, with the primary control station, will then be added for testing the capability of the control for this buildup configuration. The addition of Station Module 4 will complete the assembly of one station volume (or sub-station). Integrated tests will be conducted to verify compatibility of all subsystems and their control from the primary console. Next, Station Module 1 will be berthed to its port in Volume 2 and transfer of control will be demonstrated.

General objectives (grouped by subsystems) to be resolved on the CAV, within the limits of 1 g and the onboard instrumentation, are as follows:

R-1. Verify functional compatibility of RCS with other subsystems and GSE.

R-2. Verify prototype RCS equipment EMC.

R-3. Verify the ability to check out the RCS using OBCO.

H-2. Verify the suitability of the work and rest arrangements for the comfort and well-being of the crew.

H-3. Validate suitability of the basic crew timelines.

H-4. Verify crew proficiency in subsystem operations and in diagnosing malfunctions (if they occur).

H-5. Verify the suitability of man-machine relationships during performance of crew tasks in the controlled environments of the representative module(s).

H-6. Verify GFE interface compatibility under actual controlled environments in a representative module(s).

H-8. Demonstrate that correct level of lighting is provided in representative modules.

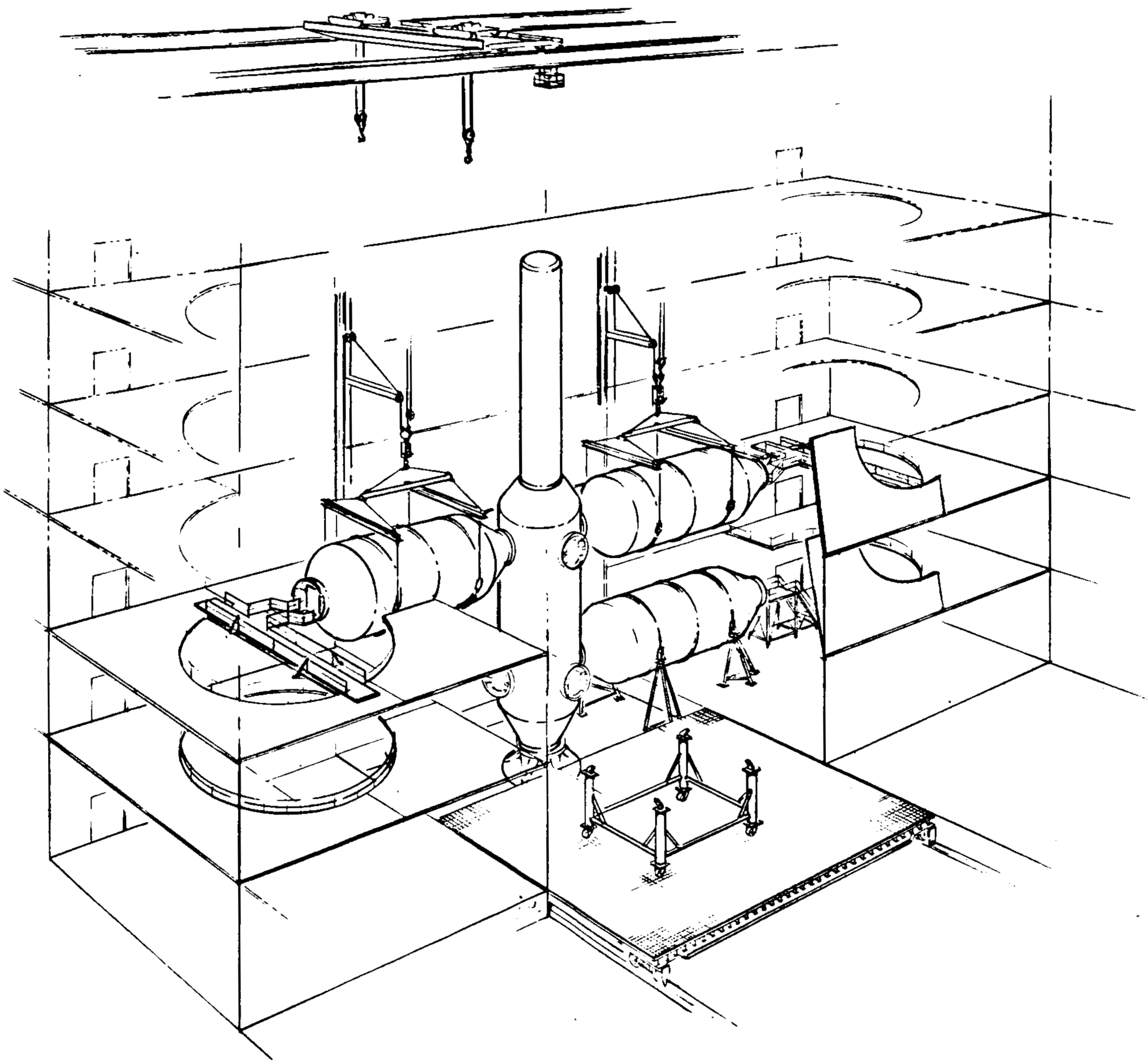


Figure 2-1. Compatibility Assessment Vehicle

E-1. Demonstrate the suitability of the ECLSS checkout procedures

E-2. Verify accessibility of ECLSS equipment for installation, inspection, maintenance, and repair.

E-3. Demonstrate functional compatibility of the ECLSS with all interfacing subsystems, GSE, and facility interfaces.

E-4. Demonstrate intersystem electromagnetic compatibility (partial) between ECLSS and all interfacing subsystems.

E-5. Demonstrate suitability (partial) of the coldplate design to remove heat at the design conditions.

E-6. Demonstrate suitability of the thermal control coating protective shield.

E-9. Verify capability to control humidity in all modes of operation.

E-10. Verify the ability to control contaminants and toxicity with hydrogen depolarizer and catalytic oxidizer units.

E-11. Demonstrate ability of ECLSS to maintain proper O_2/H_2 partial pressure relationships.

E-12. Demonstrate ability of the ECLSS to maintain correct temperature at coldplate inlets.

E-13. Demonstrate the ability to control water purity with sterilization control components.

E-14. Demonstrate the ability to reclaim water with vapor compression stills and associated components.

E-15. Demonstrate the ability to product O_2/H_2 at the required rate with electrolysis stacks installed in a representative module(s).

E-16. Demonstrate the ability to extract all water collected in the various condensing heat exchanges.

E-17. Demonstrate the ability to limit ECLSS equipment noise to acceptable limits with pumps, fans, and blowers installed in representative module(s).

E-18. Demonstrate that the atmospheric control can be balanced and fans strategically located for efficient air circulation (for 1 g operation).

E-19. Demonstrate that no spillage occurs and no air is trapped in liquid lines when IFRU's are removed and replaced.

E-22. Demonstrate (to the extent possible) that corrosion will not be a problem.

A-1. Verify ability of OBCO to status the solar arrays (simulator).

A-2. Verify ability to handle, install, and align the solar arrays to the power module (partial).

A-15. Verify ability of the on-array switching circuits to control the power from the array (simulator).

I-1. Demonstrate self-check capability of the DPA.

I-2. Demonstrate the accessibility of the ISS equipment for installation, maintenance, and repair when installed in representative modules.

I-3. Demonstrate functional compatibility of the ISS with interfacing subsections GSE and facility interfaces.

I-4. Demonstrate EMC with modules berthed in same manner as in orbit.

I-5. Demonstrate the ability of the ISS to switch from one mode to another (i.e., voice, video, data, internal, etc.).

I-7. Demonstrate the compatibility of all communication functions.

I-8. Demonstrate integration and compatibility of all independently developed checkout and statusing routines.

I-9. Demonstrate the ability of the DPA to control EPS circuit breakers, timing signals, electrical load management, etc.

I-12. Verify method for compensating for misalignment of directive antenna.

I-16. Demonstrate the ability of the DPA to status performance of subsystems by comparison with stored trend data.

I-17. Verify adequacy of all displays and controls as installed in a representative module.

I-18. Demonstrate executive control functions through the master executive program.

I-19. Demonstrate the ability to use all computer capability in an effective manner (scheduling of DPA).

I-20. Demonstrate computer capability to plan and schedule mission operations.

I-21. Demonstrate the ability of the semi-omni antenna to switch properly as commanded.

I-25. Demonstrate capability of the wide-band digital recorder

I-23. Demonstrate the ability of the input/output units to handle pulse train data at the design rate.

I-24. Demonstrate the ability of the crew to make minor software changes.

I-26. Demonstrate the proper operation of the data bus in station noise environment.

I-27. Demonstrate the ability of the DPA to control all functions of the ECLSS.

I-30. Demonstrate ability to transfer control from primary control center to secondary control center.

I-31. Demonstrate ability of ISS to control all functions of the G&C.

G-1. Verify ability of G&C to perform all control modes.

G-2. Demonstrate compatibility of software with all preprocessor functions.

G-3. Validate procedures for orbital maintenance of G&C.

G-6. Demonstrate adequacy of the G&C checkout procedures.

G-7. Demonstrate functional compatibility of G&C with interfacing subsystems, GSE, and facility interfaces.

G-8. Demonstrate electromagnetic compatibility of G&C with interfacing subsystems.

G-9. Calibrate and determine the accuracy of the alignment of optical and inertial devices to MSS module axis.

G-16. Demonstrate the ability to detect G&C electromechanical impending failures and provide warning to the crew (if they occur).

G-19. Demonstrate ability of stabilization system to stabilize initial modules.

B-1. Verify functional compatibility of all electrical and fluid interfaces across the berthing interface.

P-1. Verify compatibility of inverters with the ISS computer.

P-2. Verification of the power distribution system checkout procedures.

P-3. Verify the power conditioning system checkout procedures.

P-4. Verify functional compatibility of EPS with other subsystems, GSE, and facility interfaces.

P-5. Demonstrate accessibility of EPS equipment and components for installation, inspection, and maintenance.

P-6. Verify electromagnetic compatibility of the EPS with other subsystems, GSE, and facility interfaces.

P-7. Verify capability of the EPS to operate successfully to the normal and maximum electrical load profile.

P-8. Verify ability to dissipate the heat generated by the EPS.

P-9. Demonstrate ability of the energy storage device to adequately meet peak power demands.

P-10. Demonstrate compatibility of solid-state circuit breakers with the ISS computer.

P-12. Verify capability to prevent overheating of wire bundles.

P-13. Demonstrate adequacy of protective circuitry to prevent propagation of component failure.

P-14. Demonstrate compatibility of inverters and ISS logic with all MSS electrical loads.

P-15. Demonstrate the ability to verify the fault detection circuits while subsystems are operating normally.

P-16. Verify that noise level of all magnetic noise generators is within acceptable limits.

P-17. Demonstrate capability to synchronize all AC units operating in parallel using CTE.

P-19. Verify ability of fuel cells and energy storage combination to meet emergency loads.

S-9. Verify air-tightness of the pressure shell of such ground test module.

2.7 SUBSYSTEM DEVELOPMENT

Development of the subsystems will utilize both prototype and flight-type equipment and will include tests from early feasibility evaluations through development, development integration, qualification, and acceptance. Integrated tests with interfacing subsystems will take place upon manufacturing completion, module integration, and integrated module checkout.

Descriptions of subsystems development are given in the following paragraphs.

2.7.1 REACTION CONTROL SUBSYSTEM (RCS)

The major functions of the reaction control subsystem consist of propellant accumulator, feed controls, and engines. Major interfaces are with the EPS and ECLSS. The RCS subassemblies and assemblies will be individually developed and qualified. The RCS development requirements are listed in Table 2-6 (Section 2.11). Tests to satisfy these requirements will utilize prototype hardware and will include individual hardware development as well as integrated testing of the subsystem as a whole, demonstrating the functions of the RCS as well as the simulated interfaces. Flight hardware will be qualified and accepted as shown in Table 2-1. During the manufacturing functional, module integration, and integrated module tests, the engines will not be fired; however, simulated propellants will be flowed in the system.

Table 2-1 shows the testing categories for prototype and flight hardware. The grouping of the equipment is not intended to be inclusive or restrictive but is presented to indicate possible and logical combinations of hardware and functions requiring similar testing.

2.7.2 ENVIRONMENTAL-THERMAL CONTROL/LIFE SUPPORT SUBSYSTEM

The environmental-thermal control/life support subsystem (ECLSS) has the following major functions:

1. Gaseous storage

2. CO_2 management

3. Atmospheric control

4. Thermal control

5. Water management

6. Waste management

7. Hygiene

8. Special life support

The development plan for the ECLSS includes individual hardware development and qualification, as well as integrated subsystem function development and subsystem demonstration using prototype hardware. The development requirements for the ECLSS are listed in Table 2-8 (Section 2.11.). The satisfaction of these requirements depends to a large degree on space station prototype (SSP) work being accomplished under NASA direction. Additional integration of the SSP with interfacing subsystems is planned in the continuing development programs. Flight-type hardware will be qualified and accepted as shown in Table 2-2. During the manufacturing functional checkout, module integration, and integrated module tests, the ECLSS will be checked out. However, such functions as showers and trash processing will not require operational checkout or demonstration beyond the manufacturing functional checkout.

Table 2-2 shows the testing categories to be exercised for both prototype and flight hardware. The groupings of equipment are given to indicate possible and logical combinations of equipment or functions that could be developed together.

2.7.3 STRUCTURES

Development requirements for the modular space station structure are listed in Table 2-9, Section 2.11. The majority of the development requirements will be satisfied with laboratory tests of subassemblies or assemblies. However, major structural test articles will be required for each of the unique modules, i.e., core, station module, and power module to demonstrate static, dynamic, and acoustic integrity. Multiple use will be made of the major test articles as shown in the phasing chart, Figure 2-4 (Section 2.9), and the development article logic diagram, Figure 2-2 (Section 2.8).

Table 2-1. Reaction Control System Functions, Test Categories

Reaction Control System		Feasibility	Development	Subsystem Development Integration	Individual Hardware Qualification	Individual Hardware Acceptance	Subsystem Acceptance	Manufacturing Functional	Module Integration	Integrated Module Tests
Propellant Accumulator										
H_2 accum. O_2 accum.	P F	Prototype --	Prototype --	Prototype --	Prototype Flight hardware	Prototype Flight hardware	-- Flight hardware	-- Flight hardware	--	--
Propellant Feed Controls										
Valves Regulators	P F	Prototype --	Prototype --	Prototype --	Prototype Flight hardware	Prototype Flight hardware	-- Flight hardware	-- Flight hardware at installation*	--	--
Engines Engines/mounts	P F	Prototype --	Prototype --	Prototype --	Prototype Flight hardware	Prototype Flight hardware	Prototype Flight hardware	-- Flight hardware at installation**	--	--

*Nonflow
**Nonfiring functional

Table 2-2. Environmental-Thermal Control Life Support Subsystem Functions, Test Categories

ECLSS		Feasibility	Development	Subsystem Development Integration	Individual Hardware Qualification	Individual Hardware Acceptance	Subsystem Acceptance	Manufacturing Functional	Module Integration	Integrated Module Tests
Gaseous Storage (O_2, N_2, H_2)										
Pumpdown Repressurization Leakage makeup	P	Prototype	Prototype	Subsystem prototype SSP	Prototype	Prototype	--	--	*SSP in NCDP modules	SSP in NCDP(1) modules
	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation	--	--
EPS supply	P	Prototype	Prototype	Prototype	Prototype	Prototype	--	Prototype when installed in EPS B/B	Prototype in EPS B/B in NCDP	Prototype with EPS(2) B/B in NCDP
	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation	--	--
RCS supply	P	Prototype	Prototype	Prototype	Prototype	Prototype	Prototype			(3)
	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation	--	--
CO_2 Management										
CO_2 removal	P	Prototype	Prototype	Subsystem prototype SSP	Prototype	Prototype	--	--	SSP in NCDP module	SSP in NCDP module modules
CO_2 reduction	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware at module integration	Flight hardware at integration test
Water electrolysis										
Atmospheric Control										
Circulation/ventilation	P	Prototype	Prototype	Subsystem prototype SSP	Prototype	Prototype	--	--	SSP in NCDP module	SSP in NCDP modules
Temperature Humidity Trace contaminant	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware	Flight hardware at module integration	Flight hardware at integration test
Pressure	P	Prototype	Prototype	Subsystem prototype SSP	Prototype	Prototype	--	--	SSP in NCDP modules	SSP in NCDP modules
	F	--	--	--	Flight hardware	Flight hardware	--	--	--	--
Thermal Control										
Internal Coolant Loop	P	Prototype	Prototype	Prototype	Prototype	--	--	--	SSP in NCDP modules	SSP in NCDP modules
RAM H_x Water pump package Coldplates	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation	Coldplates and XTNL cooling	Coldplates and XTNL cooling
Heat Rejection Loop										
Radiators Freon/water intercooler	P	Prototype	Prototype	Prototype	Prototype	Prototype	Prototype	--	Prototype with SSP in NCDP	Prototype with SSP in NCDP
Freon pump package Freon reservoir	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation	Ground cooling	Ground cooling

Table 2-2. Environmental-Thermal Control-Life Support Subsystem Functions, Test Categories (Cont)

ECLSS		Feasibility	Development	Subsystem Development Integration	Individual Hardware Qualification	Individual Hardware Acceptance	Subsystem Acceptance	Manufacturing Functional	Module Integration	Integrated Module Tests
Water Management										
Potable water recovery; Wash & condense recovery; Storage & purity control	P	Prototype	Prototype	Prototype	Prototype	Prototype	--	--	Prototype SSP in NCDP	Prototype SSP in NCDP
	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation		
Waste Management										
Fecal collection; Urine collection; Waste trash processing	P	Prototype	Prototype	Prototype	Prototype	Prototype	--	--	SSP in NCDP	SSP in NCDP
	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation	--	--
Hygiene										
Body washing; Hand & face washing; Housekeeping	P	Prototype	Prototype	Prototype	Prototype	Prototype	--	--	Prototype in NCDP SSP	Prototype in NCDP SSP
	F	--	--		Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation	--	--
Special Life Support										
Fire detection & control	P	Prototype	Prototype	Prototype	Prototype	Prototype	--	--	--	--
	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware**	Flight hardware**
IVA connects; PLSS servicing; Emergency O_2	P	Prototype	Prototype	Prototype	Prototype	Prototype	--	--	Prototype in NCDP	Prototype in NCDP
	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware*	--

*NCDP = NASA continuing development programs
**In modules with integrating tool
(1)Considering pumps, regulators, etc.
(2)Considering tanks, conditioning equipment, valving, etc.
(3)Considering tanks, conditioning equipment, valving, etc.

2.7.4 BERTHING

Berthing development requirements are listed in Table 2-10 (Section 2.11). Many of the structural issues of the berthing mechanism will be resolved in conjunction with those identified in Table 2-9 (Section 2.11). Functional ability of the mechanism including effects of thermal-vacuum environment will be demonstrated primarily in the laboratory utilizing subassemblies and assemblies.

2.7.5 GUIDANCE AND CONTROL

The main functions of the guidance and control subsystem include inertial reference, optical reference, RCS electronics, momentum exchange, and computation. The development requirements for the G&C subsystem are listed in Table 2-11 (Section 2.11).

Development of the G&C subsystem will include those categories of test, and types of hardware-prototype and flight type - as shown in Table 2-3. Initial tests will establish the feasibility while subsequent tests will develop and qualify prototype hardware. Integration of the various functions will be accomplished using breadboards and computer simulation. The suggested groupings shown are considered as logical or probable combinations for development.

2.7.6 ELECTRICAL POWER SUBSYSTEM DEVELOPMENT PLAN

The electrical power subsystem has the following major functions:

1. Primary power generation
2. Secondary power generation
3. Energy storage
4. Power conditioning
5. Distribution, control, and wiring
6. Lighting

The development plan for the EPS includes the individual function development and demonstration and the integration development and demonstration of these functions as a complete subsystem.

Feasibility and development tests of the prototype hardware required for these EPS functions will be accomplished individually. Individual qualification and acceptance tests of the prototype hardware will be conducted. To assure the capability of the subsystem to perform its functions, the development of prototype hardware will be integrated into a system as representative as possible of the final design. The following functional hardware will be required for integration:

Primary power generation	
Solar arrays	Simulated
Orientation drive	Prototype equipment
Power transfer	Prototype equipment
Secondary power generation	
Regenerative fuel cells	Prototype equipment
Energy storage	
Electrolysis unit	Prototype equipment
Storage tanks	Prototype equipment
Power conditioning	
Inverters	Prototype equipment
Secondary bus equipment	Prototype equipment
Distribution, control and wiring	
Busses	Prototype equipment
Wiring	Prototype equipment
Feeders	Prototype equipment
EPS controls	Prototype equipment
Circuit breakers	Prototype equipment
Contactors	Prototype equipment

Table 2-4 lists the EPS functions and indicates the types of tests to be conducted on the prototype and flight-type hardware. These groupings of functions are not to be considered as requirements, but rather are shown as possible and logical combined developments. The detailed development plan will be devised during Phase C.

Table 2-3. Guidance and Control Subsystem Functions, Test Categories

G&C		Feasibility	Development	Subsystem Development Integration	Individual Hardware Qualification	Individual Hardware Acceptance	Subsystem Acceptance	Manufacturing Functional	Module Integration	Integrated Module Tests
Inertial Reference										
Strapdown IMU	P	Prototype	Prototype	Prototype	Prototype	Prototype	--	--	--	--
Preprocessor	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware at module integration	Flight hardware at integrated checkout
Optical Reference										
Horizon tracker (optics & electronics)		Prototype	Prototype	Prototype	Prototype	Prototype	--	--	--	--
Star tracker (optics & electronics)		--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware at module integration	Flight hardware at integrated checkout
Sextant/telescope										
Preprocessor										
Navigation base										
Alignment links										
RCS Electronics										
Driver electronics	P	Prototype	Prototype	Prototype	Prototype	Prototype	--	--	--	--
Preprocessor	F	--	--	--	Flight hardware	Flight hardware	Flight hardware*	Flight hardware at installation*	Flight hardware at module integration*	Flight hardware at integrated checkout*
Momentum Exchange										
Control moment gyro	P	Prototype	Prototype	Prototype	Prototype	Prototype	--	--	--	--
Proprocessor	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware at module integration	Flight hardware at integrated checkout
Computation										
Software	P	Prototype	Prototype	Prototype	Prototype	Prototype	--	--	--	--
	F	--	--	--	Flight software	Flight software	--	Flight software at installation	Flight software at module installation	Flight software at integrated checkout

*RCS will be inhibited

Table 2-4. Electrical Power Subsystem Functions, Test Categories

EPS		Feasibility	Development	Subsystem Development Integration	Individual Hardware Qualification	Individual Hardware Acceptance	Subsystem Acceptance	Manufacturing Functional	Module Integration	Integrated Module Tests
Primary Power Generation										
Solar array	P	Prototype	Prototype	Simulator with EPS breadboard	Prototype	Prototype	--	--	Simulator with EPS breadboard in NCDP	EPS breadboard in NCDP
Orientation drive & power transfer	F	--	--	--	--	Flight hardware	Flight hardware	Flight hardware	Simulator with FMCV**	Simulator, C1, PM1, SM1, & FMCV
Secondary Power Generation										
Fuel cells	P	Prototype	Prototype	Prototype with EPS breadboard	Prototype	Prototype	--	Prototype when installed in breadboard	Prototype with EPS breadboard in NCDP	Prototype with EPS breadboard in NCDP
	F	--	--	--	--	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware in PM with FMCV	Flight hardware in PM with C1, SM1, & FMCV
Energy Storage										
Electrolysis unit	P	Prototype	Prototype	Prototype with EPS breadboard	Prototype	Prototype	--	Prototype when installed in breadboard	Prototype with EPS breadboard in NCDP	Prototype with EPS breadboard in NCDP
Storage tanks	F	--	--	--	--	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware in PM with FMCV	Flight hardware in PM with C1, SM1, & FMCV
Power Conditioning Inverters										
Solar array	P	Prototype	Prototype	Prototype with EPS breadboard	Prototype	Prototype	--	Prototype when installed in breadboard	Prototype with EPS breadboard in NCDP	Prototype with EPS breadboard in NCDP
Fuel cell	F	--	--	--	--	Flight hardware	--	Flight hardware at installation	Flight hardware in PM with FMCV	Flight hardware in PM with C1, SM1, & FMCV
Secondary Bus Equipment										
Autotransformers	P	Prototype	Prototype	Prototype with EPS breadboard	Prototype	Prototype	--	Prototype when installed in breadboard	Prototype with EPS breadboard in NCDP	Prototype with EPS breadboard in NCDP
Rectifier-filter	F	--	--	--	--	Flight hardware	--	Flight hardware at installation	Flight hardware in PM with FMCV	Flight hardware in PM with C1, SM1, & FMCV
Distribution, control, & wiring										
Busses	P	Prototype	Prototype	Prototype with EPS breadboard	Prototype	Prototype	--	Prototype when installed in breadboard	Prototype with EPS breadboard in NCDP	Prototype with EPS breadboard in NCDP
Wiring	F	--	--	--	--	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware in modes with FMCV	Flight hardware in all modes with FMCV
Feeders										
EPS controls	P	Prototype	Prototype	Prototype with EPS breadboard	Prototype	Prototype	--	Prototype when installed in breadboard	Prototype with EPS breadboard in NCDP	Prototype in EPS breadboard in NCDP
Circuit breakers	F	--	--	--	--	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware in modes with FMCV	Flight hardware in all modes with FMCV
Contactors										

*NCDP = NASA continuing development programs
**FMCV - Flight Module Checkout Vehicle — See Figure 2-2, Utilization Logic

Table 2-4. Electrical Power Subsystem Functions, Test Categories

EPS		Feasibility	Development	Subsystem Development Integration	Individual Hardware Qualification	Individual Hardware Acceptance	Subsystem Acceptance	Manufacturing Functional	Module Integration	Integrated Module Tests
Primary Power Generation										
Solar array	P	Prototype	Prototype	Simulator with EPS breadboard	Prototype	Prototype	--	--	Simulator with EPS breadboard in NCDP	EPS breadboard in NCDP
Orientation drive & power transfer	F	--	--	--	--	Flight hardware	Flight hardware	Flight hardware	Simulator with FMCV**	Simulator, C1, PM1, SM1, & FMCV
Secondary Power Generation										
Fuel cells	P	Prototype	Prototype	Prototype with EPS breadboard	Prototype	Prototype	--	Prototype when installed in breadboard	Prototype with EPS breadboard in NCDP	Prototype with EPS breadboard in NCDP
	F	--	--	--	--	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware in PM with FMCV	Flight hardware in PM with C1, SM1, & FMCV
Energy Storage										
Electrolysis unit	P	Prototype	Prototype	Prototype with EPS breadboard	Prototype	Prototype	--	Prototype when installed in breadboard	Prototype with EPS breadboard in NCDP	Prototype with EPS breadboard in NCDP
Storage tanks	F	--	--	--	--	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware in PM with FMCV	Flight hardware in PM with C1, SM1, & FMCV
Power Conditioning Inverters										
Solar array	P	Prototype	Prototype	Prototype with EPS breadboard	Prototype	Prototype	--	Prototype when installed in breadboard	Prototype with EPS breadboard in NCDP	Prototype with EPS breadboard in NCDP
Fuel cell	F	--	--	--	--	Flight hardware	--	Flight hardware at installation	Flight hardware in PM with FMCV	Flight hardware in PM with C1, SM1, & FMCV
Secondary Bus Equipment										
Autotransformers	P	Prototype	Prototype	Prototype with EPS breadboard	Prototype	Prototype	--	Prototype when installed in breadboard	Prototype with EPS breadboard in NCDP	Prototype with EPS breadboard in NCDP
Rectifier-filter	F	--	--	--	--	Flight hardware	--	Flight hardware at installation	Flight hardware in PM with FMCV	Flight hardware in PM with C1, SM1, & FMCV
Distribution, control, & wiring										
Busses	P	Prototype	Prototype	Prototype with EPS breadboard	Prototype	Prototype	--	Prototype when installed in breadboard	Prototype with EPS breadboard in NCDP	Prototype with EPS breadboard in NCDP
Wiring	F	--	--	--	--	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware in modes with FMCV	Flight hardware in all modes with FMCV
Feeders										
EPS controls	P	Prototype	Prototype	Prototype with EPS breadboard	Prototype	Prototype	--	Prototype when installed in breadboard	Prototype with EPS breadboard in NCDP	Prototype in EPS breadboard in NCDP
Circuit breakers	F	--	--	--	--	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware in modes with FMCV	Flight hardware in all modes with FMCV
Contactors										

*NCDP = NASA continuing development programs
**FMCV - Flight Module Checkout Vehicle — See Figure 2-2, Utilization Logic

Tables 2-12 and 2-13 (Section 2.11) list the development requirements for the power conditioning and distribution subsystems and solar arrays, and indicate the type of tests to be conducted as well as the hardware required for resolution.

2.7.7 INFORMATION SUBSYSTEM

The main functions of the information subsystem consist of the following:

1. Data processing, including acquisition, distribution, timing, and processing control

2. Command/control and monitoring - displays

3. Software - both program and storage

4. Communications - external and internal

Early development of the information subsystem will be accomplished as advanced development tasks which will result in prototype hardware - breadboard C&D, and DPA. These breadboards will be integrated with other prototype subsystems, or partial subsystems in the NASA continuing development programs.

Development requirements for the ISS are listed in Table 2-14 of Section 2-11 while the categories of tests planned for both prototype and flight hardware are shown in Table 2-5. Detailed development plans for the ISS will be prepared during the later phases of the MSS program.

Table 2-5. Information Subsystem Functions, Test Categories

Information Subsystem		Feasibility	Development	Subsystem Development Integration	Individual Hardware Qualification	Individual Hardware Acceptance	Subsystem Acceptance	Manufacturing Functional	Module Integration	Integrated Module Tests
Data Processing										
Acquisition	P	Prototype	Prototype	DPA bread-board prototype	Prototype	Prototype	--	--	Prototype in NCDP program	--
Processing										
Computation	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware at module integration	Flight hardware at integration checkout
Memory(s) OMA										
Distribution										
Timing										
Processing control										
Command/Control & Monitor										
Operational display/control	P	Prototype	Prototype	Prototype in C&D breadboard	Prototype	Prototype	--	--	Prototype in NCDP program	--
Experiment display/control	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware at module integration	Flight hardware at integration checkout
Remote display/control (includes commander backup)										
Portable fault isolation and maintenance display/control	P	Prototype	Prototype	Prototype	Prototype	Prototype	--	--	--	--
Data displays/alarms	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware at module integration	Flight hardware at integration checkout
Software										
Program-supervisory, application, support										
Storage—tape/film										
Communication (external)	P	Prototype	Prototype	TBD	Prototype	Prototype	--	--	Partial in NCDP	--
Voice	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware installation	Flight hardware** module integration	Flight hardware** at integration checkout
Text/facsimile										
TLM-system, experiment, EVA										
Command, control										
Computer data										
Ranging										
TV—B/W/color										
Internal	P	Prototype	Prototype	TBD	Prototype	Prototype	--	--	Partial in NCDP	--
CCTV	F	--	--	--	Flight hardware	Flight hardware	Flight hardware	Flight hardware at installation	Flight hardware at module integration	Flight hardware at integration checkout
Audio/video distribution										
Entertainment/paging										
Digital data distribution										
Record/playback audio, video, digital										

*NCDP = NASA continuing development programs
**Text/facsimile not tested here

2.8 DEVELOPMENT ARTICLES UTILIZATION

Multiple use of test articles is a goal of the development program. Figure 2-2 details the logic of the usage of the several development modules while Figure 2-3 summarizes the functions they accomplish. Figure 2-4 presents a time-phased chart of the logic giving the approximate time spans for manufacturing, subsystem installation and checkout, and test spans for the major test articles. The checkout of the initial station modules using the refitted development vehicles is also shown.

2.8.1 DEVELOPMENT MODULE LOGIC

Development modules are those modules required to conduct structural integrity tests and dynamic tests, plus two additional modules required to make up the complete compatibility assessment vehicle. (See following list; letters in parenthesis refer to the master phasing chart identification.)

1. Power Boom 1 (F) will be utilized initially for structural integrity testing, then have secondary structure and prototype subsystems installed to become one of the modules comprising the compatibility assessment vehicle. It will subsequently be used in the flight vehicle acceptance tests as shown.

2. Core Module 3 (E) will be used exclusively for structural integrity testing.

3. Station Module 3C (B) will be used initially to demonstrate the structural integrity of the station modules. Secondary structures and prototype subsystems will then be installed for compatibility assessment vehicle (CAV) tests. Following CAV tests, the No. 3 station module will be refitted with flight subsystems and used in support of initial and later flight module acceptance.

4. Core Module 1 (A) will be fitted immediately with prototype subsystems and will become the central unit on which the CAV is assembled. It will be used for development tests of the CAV and stored when it is replaced by Core Module 2 (C) at the start of acceptance vehicle buildup.

5. Station Module 4c (D) will be used in a similar manner, having secondary structure and dummy subsystems installed for dynamic tests. Upon completion of the dynamic tests, the prototype subsystems will be installed, the module checked out separately, then berthed to Core Module 1 as an element of the CAV for integrated module tests. After the integrated tests, this module will be updated by the installation of flight subsystems, and used during the second phase of flight module acceptance in the MSV.

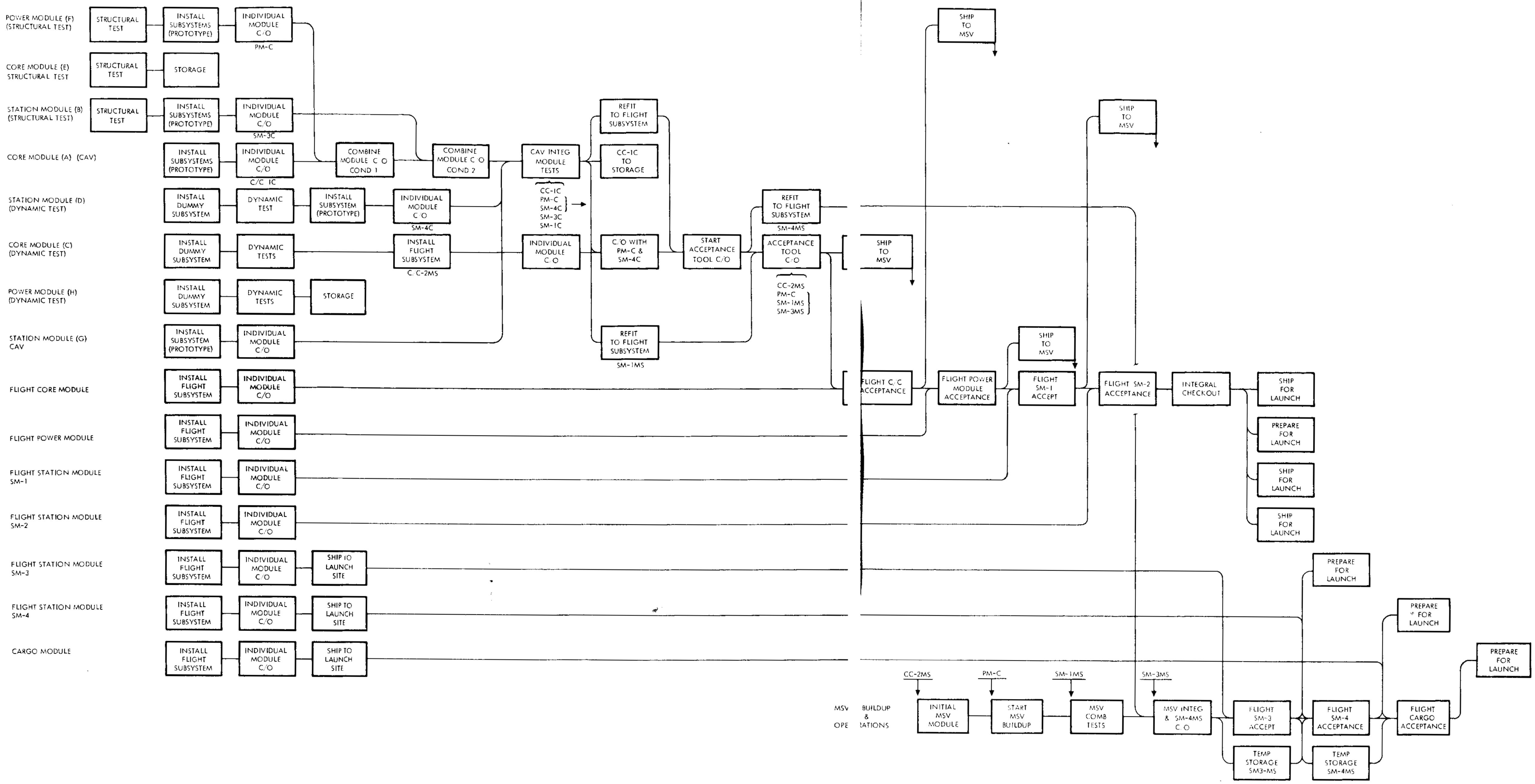
6. Core Module 2 (C) is planned as a dynamic test module, therefore will have secondary structure and dummy subsystems installed. Upon completion of the dynamic tests, the dummy subsystems will be replaced with a flight type and the module will be assembled with the power boom, Station Modules 3C, 4C, and 1C to support the initial flight module acceptance tests. With the substitution of the flight core module in the configuration for acceptance, this core module No. 2 will be prepared for and shipped to the launch site to initiate the assembly of the mission support vehicle.

7. Power Boom 2 (H) will be utilized for dynamic tests only, with the secondary structure and dummy subsystems installed. Upon completion of these tests, the boom will be deactivated.

8. Station module 1C (G) will have prototype subsystems installed, undergo individual module checkout, then will be assembled into the CAV. Following integrated module tests, it will be refitted with flight-type subsystems and assembled with Core Module 2, Station Module 3C, and the power boom to accept the flight modules. When Flight Module 1 is installed in the acceptance assembly, this module will be prepared for and shipped to the launch site to support the mission operations with Core Module 2 as the MSV.

9. Flight Station Modules 1, 2, 4, and core and power modules will each be installed in the flight module acceptance test vehicle as shown in Figure 2-2, then shipped to the launch site. The flight core module, power boom, and Station Modules 1 and 2 will be tested as a unit prior to shipment of any of these modules for launch.

10. Flight Station modules 3 and 4, as well as the cargo module, will receive an individual module checkout of the manufacturing site, then shipped to the launch site for acceptance testing in the MSV. Launching will follow the acceptance tests


POWER MODULE (F) (STRUCTURAL TEST)
CORE MODULE (E) STRUCTURAL TEST
STATION MODULE (B) (STRUCTURAL TEST)
CORE MODULE (A) (CAV)
STATION MODULE (D) (DYNAMIC TEST)
CORE MODULE (C) (DYNAMIC TEST)
POWER MODULE (H) (DYNAMIC TEST)
STATION MODULE (G) CAV
FLIGHT CORE MODULE
FLIGHT POWER MODULE
FLIGHT STATION MODULE SM-1
FLIGHT STATION MODULE SM-2
FLIGHT STATION MODULE SM-3
FLIGHT STATION MODULE SM-4
CARGO MODULE
STRUCTURAL TEST
INSTALL SUBSYSTEMS (PROTOTYPE)
INDIVIDUAL MODULE C/O
PM-C
STORAGE
SM-3C
C/C 1C
INSTALL DUMMY SUBSYSTEM
DYNAMIC TEST
DYNAMIC TESTS
INSTALL FLIGHT SUBSYSTEM
SHIP TO LAUNCH SITE
COMBINE MODULE C O COND 1
COMBINE MODULE C O COND 2
INSTALL SUBSYSTEM (PROTOTYPE)
INDIVIDUAL MODULE C O
SM-4C
C C-2MS
CAV INTEG MODULE TESTS
CC-1C
PM-C
SM-4C
SM-3C
SM-1C
REFIT TO FLIGHT SUBSYSTEM
CC-1C TO STORAGE
C/O WITH PM-C & SM-4C
SM-1MS
START ACCEPTANCE TOOL C/O
SM-4MS
ACCEPTANCE TOOL C/O
CC-2MS
SM-1MS
SM-3MS
SHIP TO MSV
FLIGHT C/C ACCEPTANCE
FLIGHT POWER MODULE ACCEPTANCE
FLIGHT SM-1 ACCEPT
FLIGHT SM-2 ACCEPTANCE
INTEGRAL CHECKOUT
SHIP FOR LAUNCH
PREPARE FOR LAUNCH
MSV BUILDUP & OPERATIONS
INITIAL MSV MODULE
START MSV BUILDUP
MSV COMB TESTS
MSV INTEG & SM-4MS C O
FLIGHT SM-3 ACCEPT
TEMP STORAGE SM3-MS
FLIGHT SM-4 ACCEPTANCE
TEMP STORAGE SM-4MS
FLIGHT CARGO ACCEPTANCE

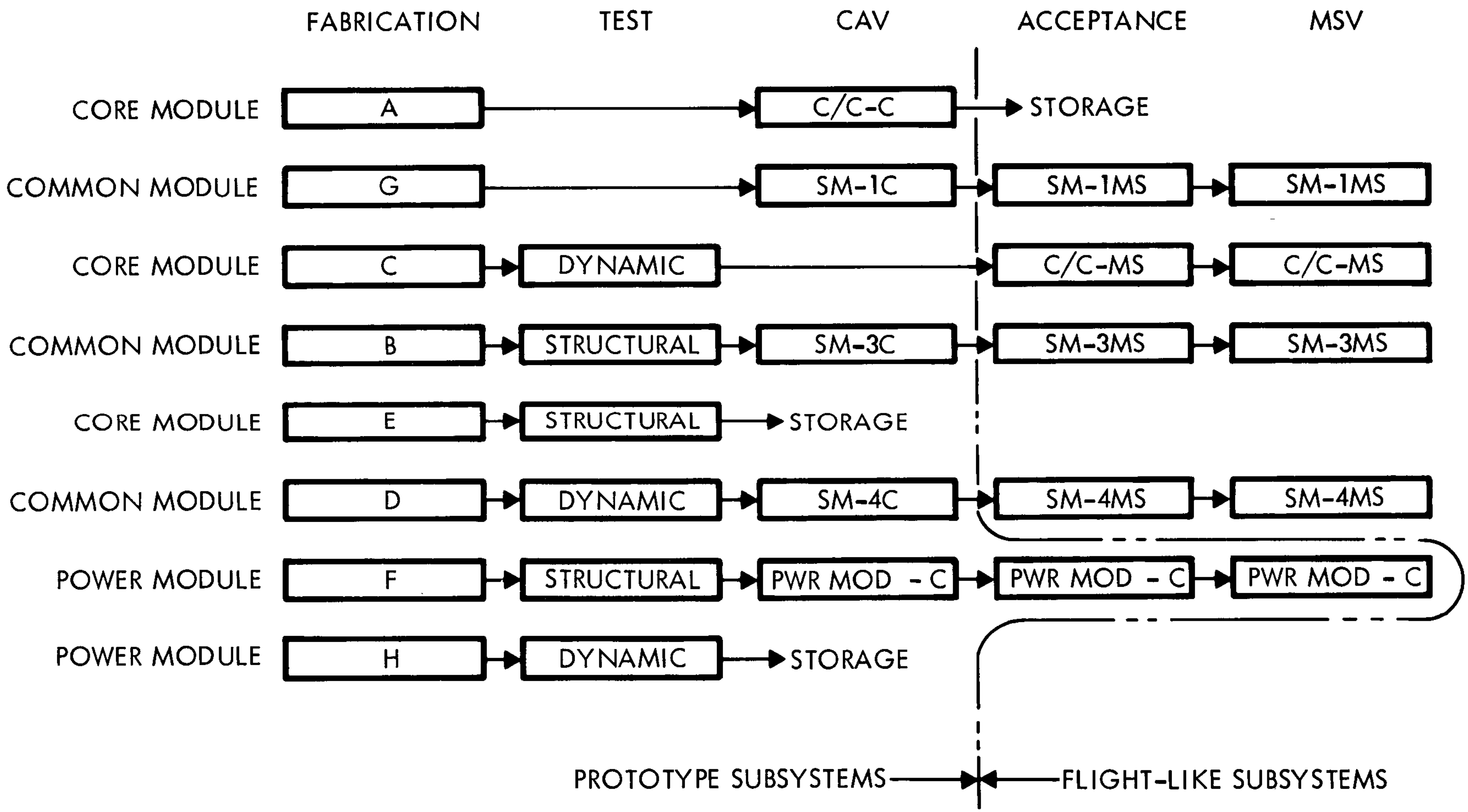
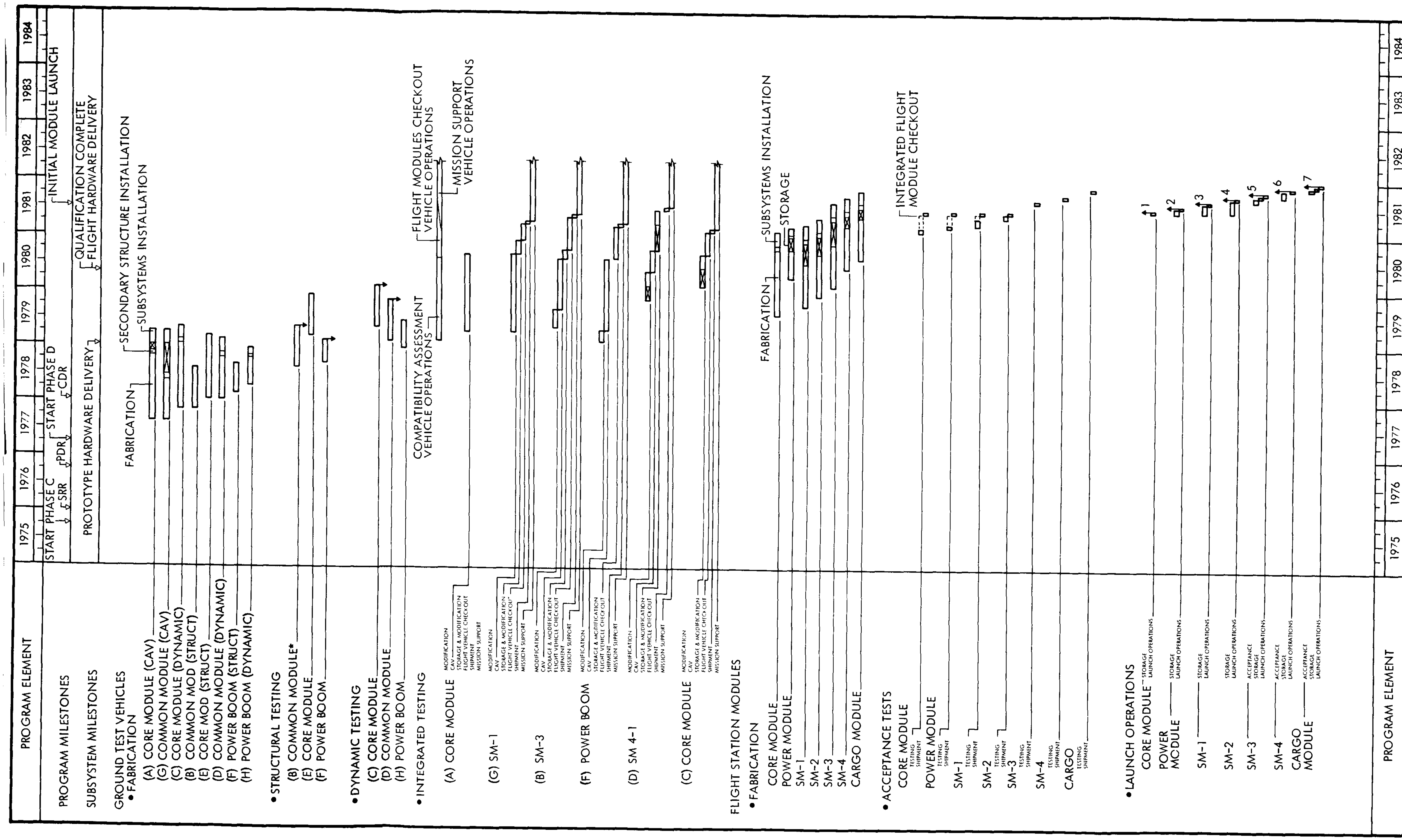


Figure 2-3. Utilization and Flow Summary of Major Test Hardware



NOTE:
*1. CARGO MODULE STRUCTURAL TESTING, CONSIDERED TO BE A TEST CONDITION OF THE COMMON MODULE
2. ↓ INDICATES MODULE IS USED ELSEWHERE IN PROGRAM

Figure 2-4. Master Phasing Chart

2.9 MASTER PHASING CHART

Figure 2-4 is the master phasing chart showing the relative time spans and phasing for manufacturing and utilization of each of the development and flight modules. It supports the MSS project master schedule contained in SD 71-225, MSS Program Master Plan. The logic of module utilization is given in paragraph 2.8.

2.10 MAJOR TEST FACILITIES

The modular space station development program will require use of several test facilities. The most important of these are briefly described in the following paragraphs. Detailed descriptions and specifically recommended facilities are contained in Section 5 of this document.

2.10.1 STRUCTURAL TEST FACILITY

A structural test facility will be required that will be large enough to accommodate the largest modules along with loading devices necessary to conduct a static structure program. The facility must be capable of structural tests for items ranging from panels through subassemblies to full modules. Requirements are specified in Table 2-19, (Section 2.11).

2.10.2 THERMAL-VACUUM TEST FACILITY

Thermal-vacuum tests will be conducted primarily on components and subassemblies as a part of the development program for which normal aerospace industrial base laboratories will suffice. Thermal-vacuum testing of the major MSS components (modules) are not being planned, but great dependence will be placed on the representative modules proposed for the NASA continuing development programs. These major tests will be conducted at the MSC, Houston thermal-vacuum chambers.

Thermal-vacuum test requirements are shown in Table 2-21 (Section 2.11).

2.10.3 ACOUSTIC TEST FACILITY

Acoustic tests of panels and major structural subassemblies will require two facilities. A small facility will be required to subject components and subassemblies to the boost environment. In addition, a facility will be required that is sufficiently large to house the station modules individually while subjecting them to the acoustic boost environment. Acoustic levels approximately those expected in the shuttle bay will be required. Requirements are specified in Table 2-20 (Section 2.11).

2.10.4 NEUTRAL BUOYANCY TEST FACILITY

Simulation of zero gravity for certain development tests involving the crew, such as cargo handling, crew restraints, and hatch operation, will require a neutral buoyant facility with a pool sufficiently large to accommodate the module mockup. The facility must have provisions for underwater photography of the tests being conducted.

Table 2-17 (Section 2.11) lists the zero-g simulation requirements.

2.10.5 ENGINEERING LABORATORIES

The majority of the tests to be conducted for development of the MSS will be accomplished in laboratories normally found in the industrial complex assigned the responsibility for design and development. Capabilities required include structural test (smaller items), electrical and mechanical development, pneumatic laboratory, fluid and hydraulic laboratories; and environmental laboratory.

Table 2-18 (Section 2.11) lists the development requirements to be completed in the various laboratories.

2.10.6 DYNAMIC TEST FACILITY

Evaluation of the dynamic characteristics of the space station and its subsystems will require use of a large facility capable of handling large test specimens such as completed modules and singly and possibly combinations of two modules.

Dynamic test requirements are listed in Table 2-20 (Section 2.11).

2.10.7 COMPATIBILITY ASSESSMENT VEHICLE

Combined module and integrated module tests will be conducted on several configurations of the MSS. The number and size of the modules will require a large facility capable of supporting the individual modules in the berthed configuration with the core module. Provisions must be incorporated to allow the removal of any one module to permit interchange of modules for flight checkout. Section 5 describes such a facility.

Requirements for integration-type tests are listed in Table 2-22 (Section 2.11).

2.11 SUBSYSTEM DEVELOPMENT ISSUES

Tables 2-6 through 2-14 in this section describe the development issues identified to date for each subsystem, showing the resolution processes and gross identification of the hardware required. Tables 2-15 through 2-23 groups the resolution processes into subprograms showing the tasks to be accomplished and the event being supported or constrained.

The tables are grouped here for ease of reference.

Table 2-6. Reaction Control Subsystem Development Requirements

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
R-1	Functional compatibility of RCS with other subsystems, GSE, and facility interfaces.		x								1. Soft mockup of those modules having RCS installed.
					x						2. RCS breadboard, DPA/C&D breadboard.
	Interfaces with all other subsystems must be verified as functionally compatible before earth-orbital operations begin.								x		3. Prototype RCS installed in a representative module.
									x		4. Representative module with flight-type RCS installed, connected to simulated interface.
R-2	Electromagnetic compatibility of RCS with interfacing subsystems.	x									1. None.
					x						2. RCS components for lab testing.
	RCS electromechanical components must not generate EMI which will degrade station operations such as communications, experiments, G&C, etc.				x						3. RCS breadboard, DPA/C&D breadboard.
									x		4. Prototype RCS installed in a representative module.
									x		5. Representative module with flight-type RCS installed, connected to simulated interfaces.
R-3	Development of RCS checkout procedures.	x									1. None.
					x						2. RCS breadboard, DPA/C&D breadboard.
	Adequate checkout procedures must be established utilizing available subsystem measurement and stimuli points within the ISS OBCO capability.								x		3. Prototype RCS installed in a representative module.
									x		4. Representative module with flight-type RCS installed, connected to simulated interfaces.
R-4	Accessibility of RCS equipment and components for installation, inspection, test, and maintenance.	x									1. None.
			x								2. Soft mockup of those modules having RCS installed.
	Sufficient and proper access must be provided for maintenance and repair during station life.										

Table 2-6. Reaction Control Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
R-5	Compatibility of seals and lubricants with the gaseous propellants. The oxidizing effects of O_2 and the reduction effects of H_2 could degrade seals and lubricants and possibly cause malfunctions.				x x x						1. Selected materials for lab testing. 2. RCS breadboard. 3. Prototype RCS (engineering demonstration subsystem).
R-6	Ability of RCS to operate properly after exposure to the boost environment. RCS must be designed to withstand acceleration, vibration, and acoustic forces experienced during boost.	x			x x						1. None. 2. Prototype RCS components. 3. Flight-type RCS assembly.
R-7	Ability of RCS to operate properly after prolonged exposure to earth-orbital environments. Performance or moving parts (valves, regulators, etc.) may be adversely affected by hard vacuum, temperature extermes, and cycling.				x x						1. Prototype components. 2. Prototype RCS assembly.
R-8	Effect of propellant temperatures, accumulator pressure variations, and mixture ratio extremes on RCS performance. The subsystem must perform within specified limits for all parameter extremes expected during earth-orbital operations.	x									1. None. 2. Prototype components. 3. Flight-type RCS assembly.

Table 2-6. Reaction Control Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
R-9	Ability to meet minimum impulse requirements. Space Station operational requirements require extremely small RCS impulses for precise control.				x x x						1. Prototype RCS components. 2. Prototype RCS engine assembly. 3. Flight-type RCS assembly.

Table 2-7. Habitability Subsystem
Development Requirements

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS									HARDWARE REQUIRED
		ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	
H-1	Selection, qualification, and training of crewmen.	x		x							1. None. 2. 6 DOF task analysis simulator
	Psychophysiological responses and metabolic costs of work must be established. Special training/indoctrination requirements must be determined. Preflight medical constraints must be minimized.	x									3. None.
H-2	Determination of the optimum habitability criteria.	x	x								1. None. 2. Soft mockups of work and living modules.
	Due to long tour of duty for crewmen, living quarters must be as near earth-type as possible.								x x		3. Representative modules with prototype habitability features incorporated. 4. Representative modules with flight-type habitability features incorporated.
H-3	Determination of crew tasks and associated crew equipment.	x							x		1. None. 2. Representative modules with prototype life support functions.
	A definition must be made of tasks and equipment required by crew to meet task objectives of station.								x		3. Representative modules with flight-type life support functions.
H-4	Establishment of crew operating procedures.								x		1. Representative modules with prototype subsystems installed, including all ground support equipment.
	Crew must be proficient in all tasks, including replacement operations.								x		2. Representative modules, with flight-type subsystems installed, individually connected to simulated interfaces.

Table 2-7. Habitability Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
H-5	Ability of crew to perform all machine tasks.		x								1. Soft mockup of work areas in each module.
	Crew ability to perform all man-machine tasks must be demonstrated.			x							2. Simulated control console.
					x						3. DPA/C&D breadboard, control console breadboard.
									x		4. Representative modules with primary and secondary control centers, connected to simulated interfaces.
									x		5. Station modules with primary control center and backup control center connected to simulated interfaces.
H-6	Interface compatibility of government furnished equipment (GFE) with the MSS.	x									1. None.
			x								2. Soft mockup having GFE.
	Storage and functional interfaces with all items of GFE must be demonstrated, e.g., food, PGA, medical equipment, etc.			x							3. Hard mockup of berthing port with hatches for neutral buoyant tests.
									x		4. Representative modules with prototype GFE installed.
									x		5. Representative modules having flight-type GFE, connected to simulated interfaces.
H-7	Adequacy of crew accessories and restraint devices.	x									1. None.
	Zero-g operations will require special tools, aids, and restraint devices. These must be demonstrated.		x								2. Soft mockup of work and living modules.
				x							3. Hard mockup of work area.
										x	4. Tools, restraints, sample work area.

Table 2-7. Habitability Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
H-8	Adequacy of internal lighting.	x									1. None.
	Correct level of lighting for specific functions being performed must be demonstrated.		x								2. Soft mockup of work and living modules.
									x		3. Representative modules with proto-type lighting installed.
									x		4. Representative modules with flight-type lighting installed.
H-9	Ability to transfer cargo between Shuttle and modules, between modules, and between floors.	x									1. None.
			x								2. Soft mockup of work and living modules, berthed cargo module simulated, simulated cargo.
	Transfer of cargo will be a major crew activity. Therefore, techniques and handling accessories must be optimized.			x							3. Hard mockup of berthing port (both halves), cargo transfer equipment, simulated cargo.
H-10	Adequacy of tie-down arrangements to secure cargo and all loose equipment.	x									1. None.
			x								2. Soft mockup of work and living modules, storage areas, etc.
	Cargo IFRUs, food storage, etc. must be secured for zero-g operations.			x							3. Hard mockups of cargo storage areas and simulated cargo.
H-11	Ability of suited crewman to open and close any hatch in zero-g.	x									1. None.
			x								2. Soft mockups of hatches and airlocks.
	Use of intervolume airlock in zero-g will require suited crewman to operate hatches and controls and connect umbilicals in an emergency. Operability must be demonstrated.			x							3. Hard mockup of berthing port with hatches and vestibule.
										x	4. Hard mockup of berthing port with hatches and vestibule.

Table 2-7. Habitability Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
H-12	Ability of suited crewmen to make/remove berthed interface connections (emergency mode). The large number of pressure and electrical connections within the vestibule must be made or removed when adding or removing a module. In some emergencies this might have to be accomplished while suited.	x									1. None.
			x								2. Soft mockup of berthing ports with simulated interface connections.
				x							3. Hard mockup with simulated interface connections.
H-13	Effects of long-term zero gravity on crew health and safety. Long-term zero gravity will degrade the human cardio-vascular system and decalcify the bone structure. Muscle tone also degrades but physical exercise can maintain this item to a certain extent. The ability of the crew to survive re-entry is a key issue of long-term orbital operations.									x	1. None-drug and diet research.
										x	2. Crew recreation (exercise) equipment.
										x	3. Crew recreation (exercise) equipment.

Table 2-8. Environmental Control/Life Support Subsystem Development Requirements

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
E-1	Development of ECLSS checkout procedures.	x									1. None.
					x						2. Prototype ECLSS components and subassemblies.
	Adequate checkout procedures must be established which utilize strategic subsystem measurement and stimuli points to determine the flight-worthiness of the ECLSS.								x		3. SSP installed in representative module.
									x		4. Representative module(s) with flight-type ECLSS installed.
E-2	Accessiblity of ECLSS equipment for installation, inspection, maintenance, and repair.	x									1. None.
			x								2. Soft mockup of each module having ECLSS installed.
	Sufficient and proper access must be provided for maintenance and repair during station life.								x		3. Representative module(s) with flight-type ECLSS installed.
E-3	Functional compatibility of ECLSS with interfacing subsystems, GSE, and facility interfaces.	x									1. None.
			x								2. Soft mockup of each module having ECLSS installed.
	Interfaces with other subsystems must be verified as functionally compatible before earth-orbital operations.				x						3. Prototype ECLSS components and subassemblies.
									x		4. SSP installed in representative module.
									x		5. Representative module(s) with flight-type ECLSS installed.
E-4	Electromagnetic compatibility of ECLSS with other subsystems, GSE, and facility interfaces.				x						1. Prototype ECLSS components and subassemblies.
									x		2. SSP installed in representative module.
	ECLSS components and/or subassemblies must not produce any EMI in other subsystems or be affected by the presence of EMI from other sources.								x		3. Representative module(s) with flight-type ECLSS installed.
									x		4. Flight module, with flight-type ECLSS installed, berthed to the Integration Test Tool with simulated interfaces.

Table 2-8. Environmental Control/Life Support Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
E-5	Development of coldplate approach.	x									1. None
	Coldplate design must include redundant cooling paths, allow easy installation of IFRUs, etc.				x						2. Prototype coldplates and simulated IFRUs (heat loads).
									x		3. SSP installed in representative module with prototype coldplates.
									x		4. Representative module(s) with flight-type coldplates installed.
E-6	Protection of thermal-control coating after installation.	x									1. None.
	A rigid means of protecting the thermal-control coating after installation and prior to launch is required.								x		2. Representative module with thermal-control coatings on representative panels.
E-7	Fabrication of ECLSS insulation panels.	x									1. None.
	Lightweight construction of insulation panels will require new and efficient manufacturing processes.										
E-8	Ability of ECLSS to operate within specified limits after exposure to the dynamic boost environment.	x									1. None.
					x						2. Prototype ECLSS components.
							x				3. Representative module with simulated ECLSS masses and c.g. locations.
	ECLSS components must be able to survive boost environment and then operate within specified limits.				x						4. Flight-type ECLSS assemblies.

Table 2-8. Environmental Control/Life Support Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
E-9	Ability of ECLSS to maintain water vapor (relative humidity) within tolerance.	x									1. None.
					x						2. Prototype ECLSS components.
									x		3. SSP installed in representative module.
	The atmospheric humidity control unit must be able to perform at its maximum capability without compromising other ECLSS functions.								x		4. Representative module(s) with flight-type ECLSS installed.
E-10	Ability of ECLSS to adequately remove CO_2, odors, debris and contaminants.	x									1. None.
					x						2. Prototype ECLSS components.
									x		3. SSP installed in representative module.
	CO_2 and contaminants must be removed for toxicity control, odors, and debris for comfort and efficient operation.								x		4. Representative module(s) with flight-type ECLSS installed.
E-11	Ability of ECLSS to maintain proper O_2/N_2 partial-pressure relationship.	x									1. None.
					x						2. Prototype partial-pressure regulators.
									x		3. SSP installed in representative module.
	Ability to maintain correct partial-pressure ratio must be demonstrated, considering leakage, metabolic rates, etc.								x		4. Representative module(s) with flight-type ECLSS installed.
E-12	Ability of ECLSS to maintain correct temperature at coldplate inlets.	x									1. None.
					x						2. Prototype water-loop heat exchangers.
									x		3. SSP installed in representative module.
	Ability to maintain coolant temperature range for all modes of station operations must be demonstrated.								x		4. Representative module(s) with flight-type ECLSS installed.

Table 2-8. Environmental Control/Life Support Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
E-13	Ability of sterilization equipment to adequately control purity of water. Sterilization technique depends on the ability to sense potability of water and to recycle it if it is not potable. Concept must be demonstrated.	x			x				x x		1. None. 2. Prototype sterilization components. 3. SSP installed in representative module. 4. Representative module(s) with flight-type ECLSS installed.
E-14	Ability of urine, condensate, wash water and waste water recovery circuit to adequately reclaim water. Reclamation of urine, condensate, wash water, and waste water by vapor compression must be demonstrated before earth-orbital operations begin.	x			x				x x		1. None. 2. Prototype ECLSS components and sub-assemblies. 3. SSP installed in representative module. 4. Representative module(s) with flight-type ECLSS installed.
E-15	Ability of water electrolysis unit to produce O_2/H_2 from H_2O at required rate must be demonstrated. The ability of the wick feed to product O_2/H_2 from H_2O at required rate must be demonstrated.	x			x				x x		1. None. 2. Prototype electrolysis units. 3. SSP installed in representative module. 4. Representative module(s) with flight-type ECLSS installed.
E-16	Ability of all condensers to extract water efficiently The technique of collecting and extracting all water collected must be demonstrated.	x			x				x x		1. None. 2. Prototype condensers. 3. SSP installed in representative module. 4. Representative module(s) with flight-type ECLSS installed.

Table 2-8. Environmental Control/Life Support Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
E-17	Ability to limit equipment noise to acceptable level.	x									1. None.
					x						2. Prototype pumps, fans, blowers, etc.
	The various sources of noise inherent in the ECLSS must be controlled so that they are not a source of fatigue.								x		3. SSP installed in representative module.
									x		4. Representative module(s) with flight-type ECLSS installed.
E-18	Balance subsystem for proper air flow in each module.	x									1. None.
			x								2. Soft mockup of each module having airflow equipment.
	Efficient circulation of air within the station will depend on proper placement of fans, diffusers, and registers.								x		3. SSP installed in representative module.
									x		4. Representative module(s) with flight-type ECLSS installed.
E-19	Ability to remove and replace IFRUs without spillage or trapping air in liquid lines.	x									1. None.
					x						2. Prototype disconnects.
	Spilled liquids could be a hazard to personnel and equipment. Trapped air could be difficult to remove or affect operation.								x		3. SSP installed in representative module.
									x		4. Representative module(s) with flight-type ECLSS installed.
E-20	Degradation of thermal-control coating by the venting of gases and fluids.	x									1. None.
	Experience has shown that vented fluids stay in immediate vicinity of the spacecraft. Heat rejection may suffer because of control-coating contamination.									x	2. Thermal-control coatings on representative panels.

Table 2-8. Environmental Control/Life Support Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
E-21	Degradation of thermal-control coating by RCS plume effects. RCS engine plumes produce potential contamination, heating, erosion, etc., which can reduce performance of external radiators.	x			x						1. None. 2. RCS engines, sample thermal-control coatings on representative panels.
E-22	Corrosion effects of the water management assembly. It is necessary to demonstrate that corrosion will not be major problem before earth-orbital operations begin.				x				x x		1. None. 2. SSP installed in representative module. 3. Representative module(s) with flight-type ECLSS installed.
E-23	Ability of pump-down components to operate in time period allotted. Each deberthing and airlock operation must include a pump-down of the port/airlock in order to conserve atmosphere. Pump-down components must operate in time allotted.	x			x			x			1. None. 2. Prototype pump-down components, hard mockup of the vestibule between berthing port hatches. 3. Representative module(s) with pump-down equipment installed.

Table 2-9. Structural Subsystem Development Requirements

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
S-1	Accessibility to interior pressure walls for inspection, maintenance, and repair. Adequate clearance must be provided for periodic inspection and possible repair of all interior pressure shell walls.	x	x								1. None. 2. Soft mockup of core module, power module, and common station modules.
S-2	Effects of acoustics on structural integrity. Incomplete definition of acoustic levels and complexity of the module structure makes the assessment of the module structural integrity difficult.	x			x		x				1. None. 2. Structural test panels (two each of representative designs - w/radiators, w/o radiators, etc.). 3. Representative modules for acoustic tests.
S-3	Ability of module structure to sustain all loads imposed by attached equipment, as a result of ground handling, checkout, boost, landing, emergency, etc. Equipment attached to floors and frames will exert large shear and bending loads when subjected to high acceleration/deceleration forces.	x			x	x					1. None. 2. Representative floor section, structural components, such as: frames, attach points, etc. 3. Representative modules (core, power, and station).

Table 2-9. Structural Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
S-4	Ability of modules to withstand the effects of combined boost environment.	x			x						1. None. 2. Representative structural components, such as: joints, splices, etc. 3. Representative modules (core, power, and station).
	Internal temperature differentials (-300 to +350), combined with maximum boost loads and vibration/acoustic environment, represents a combined stress level which is difficult to determine analytically.					x					
S-5	Ability to adequately vent module insulation without damage. Insulation might be damaged by rapid ascent of module coupled with ambiguous path for trapped air to escape.	x			x						1. None. 2. Structural test panels with insulation installed (two each of representative designs - w/radiators, w/o radiators, etc.).
S-6	Transmissibility of acoustic energy to subsystem equipment.	x			x						1. None. 2. Structural test panels (two each of representative designs- w/radiators, w/o radiators, etc.).
	Degree of transmissibility (or attenuation) inherent in the station structure must be known as accurately as possible in order to establish a realistic dynamic environment requirement for qualification and/or acceptance tests of subsystems.						x				3. Representative modules with simulated equipment installed (mass and c.g. locations).

Table 2-9. Structural Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
S-7	Sensitivity to high-g oscillatory vibrations along the X-axis. Certain flight conditions of the Shuttle can cause severe vibration effects. The module mountings, module structure, and equipment mountings must be designed to minimize these effects on MSS installed equipment.	x					x				1. None. 2. Representative modules with simulated equipment installed (mass and c.g. locations).
S-8	Ability of multilayer insulation to withstand acoustics, vibration, and acceleration loads. Insulation is highly susceptible to damage from the dynamic boost environment.	x			x						1. None. 2. Structural test panels with insulation installed (two each of representative designs - w/radiator, w/o radiator, etc.).
S-9	Air-tightness of pressure shell. The many mechanical joints, pressure seals, ports, and airlocks must be designed and processes rigidly controlled to preclude excessive leakage of inner pressure shell.	x			x			x	x		1. None. 2. Prototype seals and gasket materials. 3. Representative module with airlock attached. 4. Each flight module.

Table 2-9. Structural Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
S-10	Ability to clean/replace windows without EVA.	x									1. None.
	High-quality optical windows, required for SOSI, must be capable of being replaced/cleaned without EVA after degradation from deposits of products of combustion, micro-meteoroid impacts, etc.		x								2. Hard mockup of representative window.
					x						3. Prototype window.
								x			4. Representative module section with window assembly.
S-11	Adequacy of micro-meteoroid protection of modules.	x									1. None.
	Design of micro-meteoroid bumper must minimize damage to modules which could occur during ten-year life.				x						2. Bumper sample materials.
S-12	Selection of optimum method of repairing micro-meteoroid damage.				x						1. Sample materials for repairing micro-meteoroid damage.
	Method of repairing micro-meteoroid damage must be easy, fast, and permanent.							x			2. Representative module section and selected materials for repairing micro-meteoroid damage.
										x	3. Selected materials for repairing micro-meteoroid damage.

Table 2-9. Structural Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
S-13	Ability of module structure to limit radiation dosage to prescribed limits. Radiation from all sources (solar storms, nuclear, galactic, etc.) must be absorbed by the design of the module structure.	x									1. None.
S-14	Ability to operate the airlock and flexports successfully in terms of access, pressurization, and depressurization. Operation of airlock over long life (ten years) must not jeopardize crew safety.	x									1. None.
		x									2. None - human engineering study.
			x								3. Hard mockup of airlock and hard mockup of flexport.
								x			4. Representative airlock and flexport.
S-15	Minimize thermal energy gain/loss through module structure. A method of reducing solar heat loads through the module structure is necessary in order to reduce the size and weight of ECLSS.	x									1. None.
					x						2. Sample insulations, sample TC coatings, prototype TC assemblies.
								x			3. Representative module sections.
S-16	Ability of the core module internal bulkheads to sustain maximum ΔP in either direction. Possibility exists for depressurization of either pressure volume in the core module. Bulkheads must withstand this ΔP.	x									1. None.
					x						2. Representative joints and subassemblies.
						x					3. Core module structural test article with internal bulkhead installed.

Table 2-9. Structural Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
S-17	Condensation on windows. Consensation on internal surface of windows would impair vision and conduct of experiments. Verification of lack of consation required.	x			x						1. None. 2. Prototype window assembly.
S-18	Ability of module structure to retard propagation of localized damage. Any damage resulting from micrometeoroids or docking accident, etc., must be contained and not propagate.	x			x						1. None. 2. Representative sturctural test panels.
S-19	Ability to deploy flexports between modules. The deployment mechanism must account for the longitudinal axis of adjacent modules being non-parallel because of manufacturing tolerances, berthing port installations, centerline misalignments, etc.	x	x		x			x			1. None. 2. Mockup. 3. Prototype flexports and extension mechanism. 4. Flight-type flexport and extension mechanism installed in representative module section.
S-20	Ability of flexports to withstand micro-meteoroids. The design of the flexports must account for the non-parallel longitudinal axis and not be any more susceptible to micrometeoroid damage than the primary structure.	x			x						1. None. 2. Sample bumper materials.

Table 2-10. Berthing Subsystem Development Requirements

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
B-1	Functional compatibility of electrical and fluid interfaces across the berthed interface.	x									1. None.
			x								2. Soft mockup of berthing port.
					x						3. Prototype berthing assembly (both halves) with all interfacing connections functional.
	The berthing interface must accommodate electrical power, data, conditioned air, and other gaseous interfaces for successful SO/SI. The physical and functional compatibility of these interfaces must be demonstrated.								x		4. Representative modules berthed to the Integration Test Tool with simulated interfaces.
B-2	Structural integrity of berthing mechanism during berthing maneuvers.	x									1. None.
					x						2. Prototype berthing mechanism components.
	Berthing components must latch and provide a structural attachment.				x						3. Prototype berthing assembly (both halves) for simulated berthing tests.
B-3	Ability to open and close berthing hatches from either direction.	x									1. None.
			x								2. Hard mockup of berthing hatch.
	Initial buildup and manning of the station requires entry from the Shuttle, while return to the Shuttle or emergency procedures may require opening hatch from either side.			x							3. Hard mockup of berthing hatch (neutrally buoyant facility).
B-4	Compatibility of berthing interface when module port is at either temperature extreme and module has been subjected to Shuttle bay temperature gradient.	x									1. None.
					x						2. Prototype berthing mechanism components and subassemblies.
					x						3. Prototype berthing assembly for environmental extreme exposure.
	Berthing, when the station is at either temperature extreme and the port on the module being berthed has been subjected to the Shuttle										

Table 2-10. Berthing Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
B-4	cargo bay temperature gradient (-300, +350), could be difficult to accomplish because of thermal distortion.										
B-5	Ability of berthing mechanism to operate properly after prolonged exposure to space environment.	x			x						1. None. 2. Prototype berthing mechanism components and subassemblies.
	Performance of moving parts in the berthing mechanism may be adversely affected by hard vacuum and temperature.				x						3. Prototype berthing assembly for prolonged environmental tests.
B-6	Opening and closing of berthing, flexport, and airlock hatches after combined environments of low temperature, high humidity, and 3.1-psia PPO_2.	x						x			1. None. 2. Representative module section with berthing and flexport hatches, airlock, controlled internal environment.
	Berthing and flexport hatches and airlocks are exposed to these environments under normal conditions. The occurrence of local icing could impair or prevent their operation.										
B-7	Ability of Shuttle and modules to de-berth without damage to any of the bodies.	x		x							1. None. 2. Air-levitated scale models of core module/station module with operable berthing mechanism.
	Separation dynamics (including the Shuttle and manipulator) should preclude excessive relative rotation of each body in order to prevent damage to the exterior of either one.			x							3. Prototype berthing subsystem (both halves); simulator program.

Table 2-10. Berthing Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
B-8	Ability of the berthing mechanism to operate properly at the boundary extremes of the berthing envelope.	x		x							1. None. 2. Air-levitated scale models of core module/station module with operable berthing mechanism. 3. Prototype berthing assembly; 6 DOF simulator program.
	Alignment of the berthing interface at the moment of contact will probably not be perfect; therefore, the berthing components must accommodate a certain range of lateral, angular, and velocity discrepancies.			x							
B-9	Ability to open and close berthing port environmental protective covers.	x	x								1. None. 2. Hard mockup of berthing port, hatch, and environmental cover. 3. Prototype berthing assembly.
	Buildup operations require the remote opening of ports. Normal operations require the opening and closing of the covers before and after the berthing maneuver.				x						
B-10	Ability of berthing interface seals to function through all thermal ranges.	x			x x						1. None. 2. Prototype seals. 3. Prototype berthing assembly, seals.
	Successful berthing includes the proper sealing to permit shirt-sleeve transfer and maintenance.										
B-11	Ability of berthing mechanism to disconnect remotely for return to earth.	x			x						1. None. 2. Prototype remote latch releasing mechanism. 3. Prototype berthing assembly with latch release mechanism.
	When module is being readied for return to earth, hatches will be closed and latches must be released remotely.				x						

Table 2-10. Berthing Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
B-12	Ability to connect and disconnect utility lines across the berthed interface. Two of the external utilities which are connected across the module interface have a gas collector vented to space. Because the collector is essentially a bellows design, it will be very stiff and difficult to manipulate even though the differential pressure is zero at the time the connection/disconnection is made.	x	x		x						1. None. 2. Mockup of berthing interface with gas collector installed. 3. Prototype gas collectors and disconnects.

Table 2-11. Guidance and Control Subsystem Development Requirements

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
G-1	Mechanization of the G&C control modes. Primary and backup control modes will include inertial and local vertical. These must be accomplished in the most efficient manner considering such items as RCS propellants, power, reliability and weight.	x									1. None.
					x						2. Breadboard G&C components (functions).
					x						3. Prototype G&C, DPA/C&D breadboard.
									x		4. Prototype G&C, control console, installed in a representative module.
									x		5. Representative module with flight-type G&C installed, berthed to the Integration Test Tool with subsystem interfaces.
G-2	Development of optical reference and inertial reference pre-processor software. The pre-processor functions required must have proven software to effect such functions as power conversion, D/A conversion, A/D conversion, control, computation, status, OBCO subroutines, fault detection and isolation, warning, etc.	x									1. None.
		x									2. None - general purpose computer program.
					x						3. Prototype pre-processor and software.
									x		4. Prototype pre-processor installed in a representative module with all interfering prototype subsystems.
									x		5. Representative module with flight-type G&C installed, berthed to the Integration Test Tool with simulated subsystem interfaces.
G-3	Development of inflight maintenance concepts. The ability to replace CMG subassemblies must be decided concurrently with implementation of detailed design and recorded as operational procedures. Objective is to improve costs by resupplying relatively small subassemblies rather than replacing whole assemblies.	x									1. None.
					x						2. Prototype G&C equipment.
									x		3. Prototype G&C equipment installed in a representative module.
									x		4. Representative module with flight-type G&C installed, berthed to the Integration Test Tool with simulated subsystem interfaces.

Table 2-11. Guidance and Control Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
G-4	Determine optimum CMG control laws. The vehicle control law is basically a proportional plus differential controller to determine desired command moment to be applied. Optimum configuration must be selected.	x									1. None.
					x						2. Prototype CMGs, air-bearing rig.
					x						3. Prototype CMGs.
G-5	Accessibility of G&C equipment for installation, inspection, maintenance and repair. Sufficient and proper access must be provided for maintenance and repair during station life.	x									1. None.
			x								2. Soft mockup of modules having G&C equipment installed.
G-6	Development of G&C checkout procedures. Adequate checkout procesures must be established which utilize the predetermined subsystem measurement and stimuli points.	x									1. None.
					x						2. G&C breadboard, DPA/C&D breadboard.
									x		3. Prototype G&C equipment installed in a representative module.
									x		4. Representative module with flight-type G&C installed, berthed to the Integration Test Tool with simulated interfaces.
G-7	Functional compatibility of G&C with interfacing subsystems, GSE, and facility interfaces. Interfaces with all other subsystems must be verified as functionally compatible before earth-orbital operations begin.		x								1. Soft mockup of modules having G&C equipment installed.
					x						2. G&C breadboard with simulated interfaces.
									x		3. Prototype G&C equipment installed in a representative module.
									x		4. Representative module with flight-type G&C installed, berthed to the Integration Test Tool with simulated interfaces.

Table 2-11. Guidance and Control Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
		RESOLUTION PROCESS									
G-8	Electromagnetic compatibility of G&C with interfacing subsystems.				x						1. Prototype G&C components.
					x						2. Prototype G&C subassemblies and assemblies.
	G&C components must not produce any EMI in other subsystems or be affected by the presence of EMI from other sources.								x		3. Prototype G&C equipment installed in a representative module.
									x		4. Representative module with flight-type G&C installed, berthed to the Integration Test Tool with interfacing subsystems simulated.
G-9	Alignment of optical and inertial devices.	x									1. None.
					x						2. Prototype mounting and alignment equipment.
	A method must be devised to accurately mount and align the various body-mounted sensors. The method will also minimize "stack-up" errors.								x		3. Prototype mounting and alignment equipment installed in a representative module.
									x		4. Representative modules with flight-type mounting alignment, and indicating equipment installed.
G-10	Optimize CMG control-loop performance.	x									1. None.
	Desaturation errors, as well as the effects of CMG hardware nonlinearities, will tend to distort the control-loop performance.				x						2. Prototype CMGs, air-bearing rig.

Table 2-11. Guidance and Control Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
G-11	Ability of the G&C to operate within specified limits after exposure to the dynamic boost environment.	x									1. None.
					x						2. Prototype G&C components.
							x				3. Representative module with G&C simulated masses and c.g. locations.
	The electronics must be able to survive boost environment and then operate within specified limits.				x						4. Flight-type G&C assemblies.
G-12	Determination of outer-loop dynamics.	x									1. None.
		x									2. None - general purpose computer program.
	G&C transfer functions for various configurations of the station must be known to accurately establish extent of feedback through structure.						x				3. Representative modules for dynamic testing, such as: power module, core module, common modules.
G-13	Determination of rate damping and attitude-control gains.	x									1. None.
					x						2. G&C breadboard.
	G&C must have capability to control station attitude and rate about all three axes within extremely close tolerances for experiment support.			x							3. Prototype G&C assemblies, computer program.
G-14	Determination of heat-sensitive components and assemblies.	x									1. None.
	Determination of temperature control of all critical components must be obtained before ECLSS coldplate design.				x						2. Prototype G&C components, prototype coldplates.

Table 2-11. Guidance and Control Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
G-15	Development of technique for CMG desaturation with RCS.	X									1. None.
	The ability must exist to desaturate the CMGs by some external force, such as RCS, without undue perturbations of the experiment program.				X						2. Prototype CMGs, air-bearing rig.
G-16	Ability to detect G&C electromechanical failures and provide warning.	X									1. None.
		X									2. None - general purpose computer program.
	A failure to any electromechanical device (CMGs) must be detectable, and a suitable warning must be provided to the ISS for display to and action by the crew.				X						3. Prototype G&C assemblies, DPA/C&D breadboard.
									X		4. Prototype G&C equipment installed in a representative module.
									X		5. Representative module with flight-type G&C installed, berthed to the Integration Test Tool with interfacing subsystems.
G-17	Updating of inertial measurement assembly.	X									1. None.
	Because IMU is controlled by a pre-processor, it is planned to correct mechanical drift by updating the pre-processor with star sightings and landmark data.				X						2. Breadboard IMU.
					X						3. Prototype IMU.
G-18	Servo transfer functions for manual berthing (emergency mode).	X									1. None.
		X									2. None - human engineering study.
	The very long moment arm between MSS cg and berthing port at the end of core module will greatly accentuate relative motion at the			X							3. Prototype G&C with hand controllers.

Table 2-11. Guidance and Control Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
G-18	berthing port. Servo transfer functions are critical.										
G-19	Ability of the stabilization system to stabilize initial modules.	x									1. None.
					x						2. Breadboard G&C components (functions).
					x						3. Prototype G&C.
	Stabilization is required for the early modules, prior to assembly of the station to the point of complete G&C system operation (the activation of the CMGs, etc.).								x		4. Prototype G&C installed in a representative module.
									x		5. Representative core module with flight-type G&C installed, ground power supply.

Table 2-12. Electrical Power Subsystem
Development Requirements

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
P-1	Compatibility of inverters with dedicated processors.	X									1. None.
					X						2. PCS breadboard with processor-controlled inverters
									X		3. Prototype PCS with interfacing subsystems, mounted in a representative module.
									X		4. Flight-type PCS with interfacing subsystems, mounted in a representative module.
P-2	Development of power distribution system (PDS) checkout procedures.	X									1. None.
					X						2. PDS breadboard.
	Verification of signals, switching logic, redundant paths, continuity, and overall operation of PDS is required for crew safety. Procedure must be developed and proven.								X		3. Prototype PDS with interfacing subsystem, mounted in a representative module.
									X		4. Flight-type PDS with interfacing subsystems, mounted in a representative module.
P-3	Development of power conditioning system (PCS) checkout procedures.	X									1. None.
					X						2. PCS breadboard.
	Verification of signals, voltages, continuity, redundant paths, and overall operation of PCS is required for crew safety. Procedures must be developed and proven.								X		3. Prototype PCS with interfacing subsystems, mounted in a representative module.
									X		4. Flight-type PCS with interfacing subsystems, mounted in a representative module.
P-4	Functional compatibility of EPS with other subsystems, GSE, and facility interfaces.	X									1. None.
					X						2. PCS & PDS breadboards with simulated interfaces.
	The interface with all subsystems which receive power must be demonstrated for functional compatibility prior to long-term operation.								X		3. PCS & PDS breadboards, DPA/C&D breadboard with control consoles, prototype ECLSS (SSP), installed in a representative module.

Table 2-12. Electrical Power Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
P-4											4. Flight-type PCS & PDS with all interfacing subsystems, mounted in a representative module.
P-5	Accessibility of EPS equipment and components for installation, inspection, maintenance, and repair.	x									1. None.
			x								2. Soft mockup of PCS and PDS installed in each separate module.
									x		3. Prototype PCS and PDS installed in a representative module.
	Sufficient access space must be available for IFRU replacement. Inverters, regenerative fuel cells, wire hearnesses, circuit breakers, etc., require adequate accessibility for maintenance.								x		4. Flight-type PCS and PDS installed in a representative module.
P-6	Electromagnetic compatibility of EPS with other subsystems, GSE, and facility interfaces.	x									1. None.
					x						2. EPS components and/or subassemblies.
									x		3. Prototype EPS installed in a representative module.
	Certain Space Station operations (e.g., communications) may be degraded by generation of RF and induced ripple in the ac and dc buses caused by nonlinear loads, transient load changes, and switching functions.								x		4. Flight-type EPS installed in representative module.
P-7	Optimization of EPS to the normal and maximum electrical load profiles.	x									1. None.
					x						2. PCS and PDS breadboards with simulated electrical loads.
	EPS capacity must be tailored in terms of power levels versus time in order to optimize the subsystem with respect to weight, cooling				x						3. PCS and PDS breadboards, DPA/C&D breadboard, with simulated electrical loads.

Table 2-12. Electrical Power Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
P-7	requirements, volume, etc.								X		4. Prototype PCS and PDS installed in a representative module, with simulated interfaces.
									X		5. Flight-type PCS & PDS installed in a representative module, with simulated interfaces.
P-8	Development of suitable method of conducting heat from electrical equipment.				X						1. Materials chosen for heat conduction.
					X						2. Prototype EPS components and subassemblies.
	Heat generated within electrical power conditioning equipment must be dissipated for efficient operation, requiring proper selection of materials, installation, etc.				X						3. PCS breadboard with cooling capability for vacuum testing.
									X		4. Prototype PCS installed in a representative module.
									X		5. Flight-type PCS installed in a representative module.
P-9	Ability of energy storage device to meet peak demands.	X									1. None.
					X						2. PCS & PDS breadboards with simulated electrical loads.
	Power generation of solar arrays will vary from full (sunlight) to zero (dark); therefore, energy storage device must be capable of handling peak power demands.								X		3. Prototype PCS & PDS installed in a representative module, with simulated electrical loads.
									X		4. Flight-type PCS & PDS installed in a representative module, with simulated electrical loads.
P-10	Compatibility of solid-state circuit breakers with dedicated processors.	X									1. None.
					X						2. PDS breadboard with prototype circuit breakers, DPA/C&D breadboard.
	Mechanization of the computer signals to incorporate redundant sets, ON/OFF status, etc., must be demonstrated before space operations begin.								X		3. Prototype circuit breakers, prototype EPS, and simulated interface loads.
									X		4. Flight-type EPS with subsystem interface loads.

Table 2-12. Electrical Power Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
P-11	Structural integrity of EPS subassemblies/assemblies during boost environment.	x									1. None.
					x						2. Prototype EPS subassemblies/assemblies.
					x						3. Representative module with simulated EPS masses and c.g. locations.
	EPS components must withstand all dynamic loads imposed by the boost environment in order to accomplish the mission successfully.						x				4. EPS subassemblies/assemblies, flight-type.
P-12	Overheating of wire bundles.	x									1. None.
	Harnesses must be able to dissipate heat in an efficient manner, considering possible operation in a vacuum as well as wire size (weight), raceway material, etc.		x								2. Mockups of various modules.
					x						3. PDS breadboard with cooling capability.
									x		4. Prototype EPS with simulated subsystem loads, installed in a representative module.
									x		5. Flight-type EPS with all subsystem loads, installed in a representative module.
P-13	Adequacy of protective circuitry to prevent propagation of compo-	x									1. None.
					x						2. PCS & PDS breadboards, DPA/C&D breadboard.
	Overloads, reverse currents, transients, etc., must be detected and isolated in time to prevent propagation to the other areas served by the EPS.								x		3. Prototype EPS with interfacing subsystems and simulated loads.
									x		4. Flight-type EPS with interfacing subsystem loads.
P-14	Compatibility of EPS with all Space Station loads.	x									1. None.
					x						2. PCS breadboard, ISS dedicated processor.
	High-quality power without harmonics at all load levels is required.								x		3. Prototype EPS with interfacing subsystems and simulated loads.
									x		4. Flight-type EPS with interfacing subsystem loads.

Table 2-12. Electrical Power Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
P-15	Verification of fault-detection circuits.	x									1. None.
					x						2. PCS & PDS breadboards with DPA/C&D breadboard.
	Fault-detection circuits must be capable of being verified while subsystem is operating normally and fault-detection circuit is dormant.								x		3. Prototype EPS with interfacing subsystems and simulated loads.
									x		4. Flight-type EPS with interfacing subsystem loads.
P-16	Excessive noise produced by magnetic hardware.	x									1. None.
					x						2. Prototype EPS equipment.
	Acoustic noise produced by magnetic hardware may interfere with voice communication and produce crew fatigue.								x		3. Prototype EPS subsystem with simulated interface loads.
									x		4. Flight-type EPS subsystem with interfacing subsystem loads.
P-17	Ability to synchronize ac units operating in parallel.	x									1. None.
					x						2. Prototype EPS equipment.
	The ability to synchronize ac units, using CTE pulse must be demonstrated.								x		3. Prototype EPS with prototype CTE and simulated interfacing loads.
									x		4. Flight-type EPS subsystem with interfacing subsystems.
P-18	Develop a regenerative fuel cell.				x						1. Prototype regenerative fuel cells (Vendor).
	Such a fuel cell will provide for all the major energy storage requirements. This requires integration of fuel cells/electrolysis and their operation as a subsystem including all interfaces with ECLSS for thermal control and combining certain EPS functions, e.g., energy storage with requirements for secondary power (emergency, backup, etc.).				x						2. EPS breadboard, prototype fuel cells, and DPA/C&D breadboard.

Table 2-12. Electrical Power Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
P-19	Ability of fuel cells and energy storage combination to meet emergency loads.	x									1. None.
					x						2. EPS breadboard; prototype secondary energy source; simulated electrical
	This involves the operation of electrical subsystem with solar array energy conversion, as well as other separate power generation sources; emergency loads constitute an instant demand at any time.								x		3. Prototype EPS equipment, including fuel cells and energy storage device, mounted in a representative module.
									x		4. Flight-type EPS subsystem with interfacing subsystems and simulated electrical loads.

Table 2-13. Electrical Power Subsystem Development Requirements (Solar Array)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
A-1	Development of solar array (SA) checkout procedures.	x									1. None.
					x						2. Prototype SA.
	Continuity, power output, parallel/series operation, and deployment mechanisms must be verified before systems delivery.				x						3. DPA/C&D breadboard, SA simulator.
									x		4. Representative power module with SA simulator, berthed to the Integration Test Tool with simulated subsystem interfaces.
A-2	Ability to handle, install, and align solar array.	x									1. None.
			x								2. SA mockup, power module mockup.
	Methods must be devised to package, install, and align prior to flight.								x		3. SA simulator, representative power module.
A-3	Ability of all SA components and subassemblies to operate properly after exposure to the dynamic boost environment.	x									1. None.
					x						2. SA prototype components and subassemblies.
	SA components and subassemblies must operate properly after exposure to acceleration, vibration, and acoustic forces.						x				3. Representative power module with simulated SA masses and c.g. locations.
					x						4. Flight-type SA assembly, orientation mechanism.
A-4	Ability of solar arrays to successfully withstand repeated deployment and retraction.	x									1. None.
					x						2. Selected strip assembly interconnection material.
	Operational considerations (such as solar flares, berthing, etc.) may require numerous deployments and retractions of the arrays. Cell interconnections must withstand these reversing loads.				x						3. SA strip assemblies, joined together.
					x						4. Prototype SA assembly (engineering model).

Table 2-13. Electrical Power Subsystem Development Requirements (Solar Array) (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
A-5	Ability of power-transfer device to withstand continuous SA orientation motions. Depending on orbit parameters, orientation of SA will be almost continuous, and power-transfer device (SA to power module) must be able to successfully withstand this motion without an increase in power losses or other deleterious effects.	x									1. None.
					x						2. Selected materials.
					x						3. Prototype power transfer device.
A-6	Ability to position solar arrays within prescribed sun line tolerance and response time. Cells must be oriented normal to sun to obtain maximum output. The pointing system accuracy and response must be demonstrated.	x									1. None.
					x						2. Prototype mechanism, sensing components.
					x						3. Flight-type subsystem (mechanism, sensing system), SA mass simulator.
A-7	RCS plume effects on solar cell performance. RCS engine plumes produce potential contamination, heating, surface degradation, and pressure effects which could reduce performance characteristics of solar arrays. Long-term effects must be demonstrated.	x									1. None.
					x						2. SA panel segments, RCS engines.

Table 2-13. Electrical Power Subsystem Development Requirements (Solar Array) (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
A-8	Ability to maneuver solar arrays in all required positions without shadowing or other adverse effects.	x									1. None.
	Solar cells must provide full electrical power without restricting station orientation; adverse effects on star trackers, etc., must be minimized.										
A-9	Ability to reposition solar arrays during earth shadow transit.	x									1. None.
					x						2. Prototype SA orientation mechanism and SA mass simulator.
	Solar arrays must be repositioned about 180 degrees as station transits the earth shadow.				x						3. Flight-type SA orientation mechanism.
A-10	Ability of orientation mechanism to operate properly after prolonged exposure to earth orbital environments.	x									1. None.
					x						2. Orientation mechanism components and subassemblies.
					x						3. Prototype orientation mechanism.
	Performance of the moving parts may be adversely affected by hard vacuum, temperature extremes, temperature cycling, etc.										
A-11	Dynamic doupling of SA with MSS control system.	x									1. None
					x						2. SA model for dynamic testing.
	Fundamental frequency of the SA short length in the inplane configuration could fall within the restricted range of the control system.										

Table 2-13. Electrical Power Subsystem Development Requirements (Solar Array) (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
A-12	Effects of folding up a hot solar array.	x									1. None.
					x						2. Prototype SA panel segments.
					x						3. Prototype SA assembly.
	Because of the poor thermal conductivity of the cell substrate, the hot (180 degrees) cells will not cool rapidly when folded up.										
A-13	Effect of thermal cycling on solar array performance.	x									1. None.
					x						2. SA components (cells, bus bars, etc.).
					x						3. Prototype SA panel segments.
	Thermal coefficients of cell and bus parts must be matched to minimize possibility of failures due to temperature cycling.										
A-14	Effect of SA reflectance on other MSS functions.	x									1. None.
	The possibility of sunlight reflecting into horizon sensors (for instance) and disrupting that function, could have adverse effects on experiments, etc.										
A-15	Development of "on-array" switching circuits.	x									1. None.
					x						2. Prototype SA panel segments.
					x						3. Prototype SA assembly, orientation mechanism.
	The MSS must be able to shut-off high voltage, high power coming from the SA for safety reasons. Because switching of high voltage DC current is difficult, and there is no flyable hardware of this rating available to do this task, the concept of transistors on each SA bus (8 total) was conceived to								x		4. Representative power module with SA simulator, berthed to the Integration Test Tool, with simulated subsystem interfaces.

Table 2-13. Electrical Power Subsystem Development Requirements (Solar Array) (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
A-15	effect incremental control of incoming D.C. power and to substantially improve accommodation of power failures. The increased flexibility also allows power to be put to the using device (inverter, electrolysis unit) as a function of load demand without prior allocation. Demonstration is required.										

Table 2-14. Information Subsystem Development Requirements

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
I-1	Development of data-processing assembly (DPA) self-check capability.	x									1. None.
									x		2. DPA/C&D breadboard with simulated interfaces.
	Specific parameters and subroutines must be selected or developed to verify the DPA's flightworthiness.				x						3. Prototype DPA installed in representative module.
									x		4. Station module, with flight-type DPA installed, berthed to the Integration Test Tool with simulated interfaces.
I-2	Accessibility of ISS equipment for installation, inspection, maintenance, and repair.	x									1. None.
			x								2. Soft mockup of each module having ISS equipment installed.
	Sufficient and proper accessibility must be provided for installation, maintenance, and repair during the station life.								x		3. Prototype ISS equipment installed in representative modules.
									x		4. Representative modules with flight-type ISS installed.
I-3	Functional compatibility of ISS with interfacing subsystems, GSE, and facility interfaces.	x									1. None.
					x						2. Prototype ISS components, simulated interfaces.
	Interfaces with other subsystems must be verified as functionally compatible before earth-orbital operations.				x						3. DPA/C&D breadboard with simulated interfaces.
									x		4. Prototype ISS equipment installed in representative modules.
									x		5. Representative modules with flight-type ISS installed.
I-4	Electromagnetic compatibility of ISS with other subsystems, Shuttle, GSE, and facility interfaces.	x									1. None
					x						2. Prototype ISS components, simulated interfaces.
	ISS components and/or subassemblies must not produce EMI in other subsystems or be affected by the presence of EMI from other sources.				x						3. DPA/C&D breadboard with simulated interfaces.
									x		4. Representative modules with prototype ISS installed.

Table 2-14. Information Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS									HARDWARE REQUIRED
		ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	
I-4									x		5. Representative modules with flight-type ISS installed.
I-5	Communication mode switching.				x						1. Breadboard communication terminal.
	The ISS must be able to switch from one mode to another (i.e., voice, video, data, internal, etc.).				x						2. Breadboard communication terminal, DPA/C&D breadboard.
									x		3. Station module, with flight-type ISS equipment installed, berthed to the Integration Test Tool with simulated interfaces.
I-6	Determination of antenna radiation patterns.	x									1. None.
	Radiation patterns of all planned antenna and structural influences on them must be accurately known.				x						2. Scale models of semi-directional and directive antennas.
					x						3. Full-scale semi-directional and directive antennas.
I-7	Adequacy of internal communications.	x									1. None.
	Integration of all internal communications equipment, working through primary and secondary control consoles, modules, RAMs, must be demonstrated.								x		2. Representative modules with prototype internal communication equipment installed.
									x		3. Representative modules with flight-type internal communications equipment installed.
I-8	Integration of all OBCO routines.	x									1. None.
	All subsystem routines which have been independently developed for fault detection, isolation, automatic switching, and checkout, must be integrated and demonstrated.				x						2. DPA/C&D breadboard with simulated interfaces.
									x		3. Representative modules with prototype ISS equipment installed.
									x		4. Station module, with flight-type ISS equipment installed, berthed to the Integration Test Tool, with simulated interfaces.

Table 2-14. Information Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
I-9	Ability of ISS to control EPS in all operational modes.	x									1. None.
					x						2. DPA/C&D breadboard with simulated interfaces.
	The ability of ISS DPA to control EPS circuit breakers, timing signals, load management, etc., as specified, must be demonstrated.				x						3. DPA/C&D breadboard, EPS breadboard.
									x		4. Representative modules with prototype ISS and EPS equipment installed.
									x		5. Representative modules, i.e., power module, core module, station module, with flight-type ISS and EPS equipment installed.
I-10	Ability of ISS equipment to operate properly after exposure to the dynamic boost environment.	x									1. None.
					x						2. Prototype ISS assemblies.
	ISS must operate after exposure to dynamic boost environment.						x				3. Representative module with simulated ISS masses and c.g. points.
I-11	Ability of ISS to accept ground commands.				x						1. Prototype UDL.
	ISS will be required to accept commands from ground up to end of premanning period for certain modes of control.									x	2. Prototype UDL.
I-12	Determination of most suitable method for compensating for misalignment of directive antenna.	x									1. None.
					x						2. Prototype compensating mechanism.
									x		3. Representative module with K-band directive antenna installed and prototype compensating mechanism.
	Because the high gain antenna is mounted on the extremity of certain modules, the relative motion inherent in the MSS configuration will cause a variable misalignment between antenna and MSS axes.								x		4. Representative module with K-band directive antenna installed and flight-type compensating mechanism.

Table 2-14. Information Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
I-13	Ability of directive antenna to operate properly after prolonged exposure to earth-orbital environments.	x									1. None.
					x						2. Prototype directive antenna.
					x						3. Flight-type directive antenna.
	Performance of moving parts may be adversely affected by hard vacuum and temperature cycling over long station life.										
I-14	Compatibility of both real-time and recorded data playback with telemetry ground station for high data rate and video fidelity.	x									1. None.
					x						2. Prototype T/M equipment and digital recorder.
										x	3. Prototype T/M equipment and digital recorder.
	Compatibility of station data format with TDRS and MSFN must be demonstrated.										
I-15	Performance of RF communications within circuit performance margins and expected ranges.	x									1. None.
					x						2. Selected co-ax cables and connectors.
	A determination must be made of circuit margins to assure adequate communications at all distances involved and at expected power losses between transmission and reception.										

Table 2-14. Information Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
I-16	Ability of OBCO to effectively sample and compare IFRU data to trend data.	x									1. None.
					x						2. DPA/C&D breadboard.
									x		3. DPA/C&D breadboard, EPS breadboard, prototype ECLSS (SSP).
	DPA's ability to status performance of all subsystems, compare with stored trend data, and generate commands/displays, must be demonstrated.								x		4. Representative modules; i.e., power module, core module, station module, with flight-type ISS, EPS, and ECLSS equipment installed.
I-17	Optimization of all displays and controls.	x									1. None.
			x								2. Soft mockup of each module having displays and controls.
	Subsystem information must be properly selected to allow primary and redundant control and visual display to crew for corrective action.				x						3. DPA/C&D breadboard, simulated interfaces.
									x		4. DPA/C&D breadboard, EPS breadboard, prototype ECLSS (SSP) installed in a representative module.
									x		5. Representative modules; i.e., power module, core module, station module, with flight-type ISS equipment installed.
I-18	Development of efficient techniques for implementing real-time executive control of computer complex.	x									1. None.
					x						2. DPA/C&D breadboard, simulated interfaces.
	Central processor unit must have executive control over all processing functions through master executive program. Demonstration is required.								x		3. DPA/C&D breadboard, EPS breadboard, prototype ECLSS (SSP) installed in a representative module.
									x		4. Representative modules; i.e., power module, core module, station module, with flight-type ISS equipment installed.

Table 2-14. Information Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
I-19	Development of effective scheduling of DPA.	x									1. None.
	The amount of data acquired, processed, and distributed by the DPA control processor is limited by the "equiv add" operations per second which the processor can handle.				x						2. DPA/C&D breadboard, computer complex.
									x		3. DPA/C&D breadboard, EPS breadboard, prototype ECLSS (SSP) installed in a representative module.
									x		4. Representative modules; i.e., power module, core module, station module, with flight-type ISS equipment installed.
I-20	Development of computer routines for effective mission planning and mission management.	x									1. None.
	DPA must have ample and efficient routines stored for each management function required, e.g., flight operations, station operations, planning and schedule, experiments, etc.				x						2. DPA/C&D breadboard, simulated input data.
									x		3. DPA/C&D breadboard, EPS breadboard, prototype ECLSS (SSP) installed in a representative module.
									x		4. Representative modules; i.e., power module, core module, station module, with flight-type ISS equipment installed. Simulated RAM, Shuttle, DRAM, TDRS, and Ground inputs to be provided.
I-21	Mechanization of semi-omni antenna directional switching.	x									1. None.
	Switching of semi-omni antenna is required to select the optimum "look angle" to the cooperating terminal.				x						2. Breadboard switching mechanism.
					x						3. DPA/C&D breadboard with prototype switching mechanism.
									x		4. Station module, with flight-type antenna package installed, berthed to the Integration Test Tool with simulated interfaces.

Table 2-14. Information Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
I-22	Development of long-life RF power amplifiers and RF wide-band receiving electronics for long-term exposure to free-space environments.				x						1. Prototype RF power amplifiers and receiving electronics.
					x						2. Prototype RF power amplifier and receiving electronics.
					x						3. Flight-type RF power amplifier and receiving electronics.
	RF power amplifiers and receiving electronics will be mounted on high-gain antenna and subjected to free-space environments at all times.										
I-23	Development of central processor traffic flow control technique.	x									1. None.
					x						2. Breadboard processor circuitry
	Processing of large amounts of data in extremely short time requires reduction in operating time of input/output input. Development and demonstration of functional compatibility of central processor circuitry is required.				x						3. DPA/C&D breadboard with computer inputs of data and a breadboard control console.
									x		4. Station modules with flight-type ISS equipment installed in primary control center and backup control center, berthed to the Integration Test Tool with simulated interfaces.
I-24	Development of interactive (English language) vocabulary for software mods and crew control of computer.	x									1. None.
					x						2. DPA/C&D breadboard and simulated interfaces.
	Major software changes will be made on ground. Minor changes will be made by operators. Commands will be given to DPA by means of interactive vocabulary.								x		3. DPA/C&D breadboard, EPS breadboard, prototype ECLSS (SSP) installed in a representative module.
									x		4. Representative modules; i.e., power module, core module, station module, with flight-type ISS equipment installed.

Table 2-14. Information Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
I-25	Development of high-density digital storage device.	x									1. None.
					x						2. Prototype high-density digital storage device.
	New techniques will be required for digital storage device of higher density and more rapid access time than presently available.				x						3. DPA/C&D breadboard with prototype digital storage device.
									x		4. DPA/C&D breadboard, EPS breadboard, prototype ECLSS (SSP) installed in a representative module.
I-26	Elimination of noise effect on the data bus.	x									1. None.
					x						2. Data bus breadboard.
	Because of the high bit rate of 2.8×10^6 bps, the bus must be insensitive to externally generated noise.								x		3. DPA/C&D breadboard, data bus breadboard, EPS breadboard, prototype ECLSS (SSP) installed in a representative module.
									x		4. Representative modules, with flight-type ISS equipment installed, berthed to the Integration Test Tool with simulated interfaces.
I-27	Ability of ISS to control all functions of the ECLSS.	x									1. None.
					x						2. DPA/C&D breadboard with simulated interfaces.
	The DPA must control the ECLSS in all areas (primary coolant flow, automatic mode control, etc.). All command/control functions must be demonstrated before orbital operations begin.								x		3. DPA/C&D breadboard, prototype ECLSS (SSP) installed in a representative module.
									x		4. Representative modules, having flight-type ISS and ECLSS equipment, berthed to the Integration Test Tool with simulated interfaces.

Table 2-14. Information Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	RESOLUTION PROCESS: ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
I-28	Develop the functional and design interface between the DPA and the UTE. The UTE must be available in time for subcontractor factory testing. This requires an early determination of the level of authority between the ISS and UTE, as well as the preliminary design interface.	x 	 	 	 x 						1. None. 2. DPA/C&D breadboard, related test equipment and computer inputs representing the UTE.
I-29	Establish the data format to be used for stored trend data. Because a variety of subcontractors are expected to build MSS hardware, a common format is essential for integration with acceptance and diagnostic testing.	x									1. None.
I-30	Ability to transfer command/control functions between modules. The capability will exist in the MSS to transfer control from the primary command/control center to the backup center. During orbital operations, those portions of the mass and operating memory in the backup center (which are dedicated to the switchover in a safe manner), will be continuously updated. Prior to the actual switchover, the backup operating memory (computational and instruction sections) must be reconfigured.	x 			 x x 				 x x		1. None. 2. Breadboard switchover circuitry. 3. DPA/C&D breadboard and simulated interfaces. 4. Representative modules with primary control center and backup control center, and prototype ISS equipment (control consoles) installed. 5. Station modules with primary control center and backup control center, berthed to the Integration Test Tool with simulated interfaces.

Table 2-14. Information Subsystem Development Requirements (Cont)

NO.	DEVELOPMENT ISSUE AND RATIONALE	ANALYSIS	MOCKUP	ZERO-G SIMULATION	ENGINEERING TEST LAB	STATIC ENVIRONMENT	DYNAMIC ENVIRONMENT	THERMAL-VAC ENVIRONMENT	INTEGRATION	FLIGHT DEMONSTRA	HARDWARE REQUIRED
I-30	Demonstration of this switchover capability (and back again) is required prior to flight.										
I-31	Ability of ISS to control all functions of the G&C. The various torquer options and computational options, together with the several command generator options which are controlled by the ISS display and control console, must be demonstrated before orbital operations begin.	x			x				x x		1. None. 2. DPA/C&D breadboard with simulated interfaces. 3. DPA/C&D breadboard and prototype G&C equipment installed in a representative module. 4. Representative module with flight-type G&C equipment installed, berthed to the Integration Test Tool with simulated subsystem interfaces.

Table 2-15. Analysis Subprogram

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
R-2	Electromagnetic compatibility of RCS with interfacing subsystems.	1. Conduct an analysis to determine the location of electromagnetic field-producing equipment. Determine possible need for filters and shielding.	1. RCS 100% Drawing Release.
R-3	Development of RCS checkout procedures.	1. Conduct a systems analysis to establish the key parameters and test points for checkout of RCS equipment.	1. RCS 100% Drawing Release.
R-4	Accessibility of RCS equipment and components for installation, inspection, test and maintenance.	1. Conduct a space allocation analysis to determine the clearances and tolerances for adequate access to all RCS and CSA equipment.	1. RCS 100% Drawing Release.
R-6	Ability of RCS to operate properly after exposure to the boost environment.	1. Conduct a structural analysis to size the various components and establish design margins.	1. RCS 100% Drawing Release.
R-8	Effect of propellant temperatures, accumulator pressure variations, and mixture ratio extremes on RCS performance.	1. Conduct a systems analysis to establish operational performance at the parametric extremes.	1. RCS 100% Drawing Release.
H-1	Selection, qualification, and training of crewmen.	1. Conduct crew task analysis to establish realistic limits for psychophysiological responses for each of the major tasks. 2. Synthesize the results of the crew task analysis and simulation testing into special training/indoctrination requirements. Establish minimum pre-flight medical and psychophysiological requirements based on the above synthesis.	1. Zero-g simulation tests. 2. Selection and training of first operational crew.
H-2	Determination of the optimum habitability criteria.	1. Conduct a socioarchitectural analysis to establish the general arrangement of all modules, work/rest areas, consoles, illumination, color coordination, stowage, etc.	1. Habitability 100% Drawing Release.
H-3	Determination of crew tasks and associated crew equipment.	1. Perform crew task analysis to delineate the tasks of all crewmen on a timeline basis, considering buildup sequence and experiments to be performed at each capability plateau.	1. Finalization of crew selection and training criteria.
H-6	Interface compatibility of government furnished equipment (GFE) with the space station.	1. Conduct a systems analysis to establish the operating parameters, interface dimensions, and environmental conditions to be expected during use. Create GFE ICDs.	1. Habitability 100% Drawing Release.
H-7	Adequacy of crew accessories and restraint devices.	1. Conduct a design analysis to establish the best approach for tools and associated restraint devices.	1. Habitability 100% Drawing
H-8	Adequacy of internal lighting.	1. Conduct a design analysis to establish optimum lighting levels for all areas.	1. EPS 100% Drawing Release.

Table 2-15. Analysis Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
H-9	Ability to transfer cargo between shuttle and modules and between floors of the modules.	1. Conduct a design analysis to establish the required equipment/ crew aids. Establish preliminary crew procedures.	1. Habitability 100% Drawing Release.
H-10	Adequacy of tie-down arrangements to secure cargo and all loose equipment.	1. Conduct a design analysis to establish the details of tie-down arrangements for easy use of all loose equipment during zero-g environment.	1. Habitability 100% Drawing
H-11	Ability of suited crewman to open and close any hatch in zero-g.	1. Conduct a design analysis to establish clearances and accessibility to all hatches and controls for a suited crewman.	1. Module 100% Drawing Release.
H-12	Ability of suited crewman to make/remove interface connections (emergency mode).	1. Conduct a design analysis to establish clearances and accessibility to all interface connections for a suited crewman.	1. Module 100% Drawing Release.
E-1	Development of ECLSS checkout procedures.	1. Conduct a systems analysis to establish the strategic test points, their location and stimuli requirements. Establish tolerances for each measurement.	1. ECLSS 100% Drawing Release.
E-2	Accessibility of ECLSS equipment for installation, inspection, maintenance, and repair.	1. Conduct a space allocation analysis to determine clearances and tolerances for adequate access to the equipment.	1. ECLSS 100% Drawing Release.
E-3	Functional compatibility of ECLSS with interfacing subsystems, GSE, and facility interfaces.	1. Conduct a systems analysis to establish the operational interface characteristics with each subsystem. Create ICDs for each interface.	1. ECLSS 100% Drawing Release.
E-5	Development of coldplate approach.	1. Conduct a design analysis which will incorporate all the design requirements into a simple and reliable concept.	1. ECLSS 100% Drawing Release.
E-6	Protection of thermal-control coating after installation.	1. Conduct a design analysis to establish a protective shield concept for the thermal-control coating (ground use only).	1. ECLSS 100% Drawing Release.
E-7	Fabrication of ECLSS insulation panels.	1. Conduct a design analysis of the tools and fixtures required to minimize handling, lay-up time, and waste material.	1. ECLSS 100% Drawing Release.
E-8	Ability of ECLSS to operate within specified limits after exposure to the dynamic boost environment.	1. Conduct a design analysis to size the ECLSS components and mounting provisions for the expected dynamic loads.	1. ECLSS 100% Drawing Release.
E-9	Ability of ECLSS to maintain water vapor (relative humidity) within tolerance.	1. Conduct a design analysis to size the humidity control unit for max expected capacity.	1. ECLSS 100% Drawing Release.

Table 2-15. Analysis Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
E-10	Ability of ECLSS to adequately remove CO_2, odors, debris, and contaminants.	1. Conduct a design analysis to size and establish final configuration of components for removal of contaminants and toxic elements.	1. ECLSS 100% Drawing Release.
E-11	Ability of ECLSS to maintain proper O_2/N_2 partial pressure relationship.	1. Conduct a design analysis of the partial pressure regulators to determine their ability to maintain the proper relationship between O_2/N_2.	1. ECLSS 100% Drawing Release.
E-12	Ability of ECLSS to maintain correct temperature at coldplate inlets.	1. Conduct a thermal analysis of the entire temperature control loop to establish the expected temperature range at the coldplate inlets for each mode of operation.	1. ECLSS 100% Drawing Release.
E-13	Ability of sterilization equipment to adequately control purity of water.	1. Conduct an ECLSS subsystem analysis to establish detail designs of the chemical metering device and potability sensor.	1. ECLSS 100% Drawing Release.
E-14	Ability of urine and waste water recovery circuits to adequately reclaim water.	1. Conduct a design analysis to establish the size and details of each of the functional components.	1. ECLSS 100% Drawing Release.
E-15	Ability of water electrolysis unit to produce O_2/H_2 at the required rate.	1. Conduct a design analysis to size the electrolysis stack for the required gas production rate.	1. ECLSS 100% Drawing Release.
E-16	Ability of all condensers to extract water efficiently.	1. Conduct a design analysis to size the wicks and establish all design details.	1. ECLSS 100% Drawing Release.
E-17	Ability to reclaim all wash water and condensate.	1. Conduct a design analysis to establish flow paths and size the reverse osmosis unit.	1. ECLSS 100% Drawing Release.
E-18	Ability to limit equipment noise to acceptable levels.	1. Conduct a human engineering analysis to establish acceptable noise levels for various frequencies. Incorporate noise criteria in all equipment specs.	1. ECLSS 100% Drawing Release.
E-19	Balance subsystem for proper airflow in each module.	1. Conduct a design layout to evaluate all airflow paths and best placement of fans, diffusers, and registers.	1. ECLSS 100% Drawing Release.
E-20	Ability to remove and replace IFRUs without spillage or trapping air in liquid lines.	1. Conduct a design analysis to establish a disconnect concept which will prevent spillage and trapping of air.	1. ECLSS 100% Drawing Release.
E-21	Degradation of thermal-control coating by the venting of gases and fluids.	1. Conduct a thermodynamic analysis to assess the extent of radiator degradation because of vented fluids attracted to the radiators.	1. Start of Skylab tests with vented fluids.
E-22	Degradation of thermal-control coating by RCS plume effects.	1. Conduct a design analysis to select radiator/RCS locations which reduce the degradation effects of the RCS engine plumes.	1. ECLSS 100% Drawing Release.
E-24	Ability of pump-down components to operate in time period allotted.	1. Conduct a design analysis to size the pumping components, plumbing, controls, and air receivers.	1. ECLSS 100% Drawing Release.

Table 2-15. Analysis Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
S-1	Accessibility to interior pressure walls for inspection, maintenance, and repair.	1. Design analysis to determine adequate clearance and accessibility to interior pressure walls.	1. Module Design Freeze.
S-2	Effects of acoustics on structural integrity.	1. Calculate amount of acoustic energy generated during ascent and amount of energy absorbed by the module structure. Establish design margins.	1. Lab testing of prototype structural components.
S-3	Ability of module structure to sustain all loads imposed by attached equipment as a result of ground handling, checkout, boost, landing, emergency, etc.	1. Structural analysis to determine load paths and size individual structural members and components. Consider ground handling and checkout mode, as well as dynamic boost conditions.	1. Lab testing of prototype structural components.
S-4	Ability of modules to withstand effects of the combined boost environment.	1. Structural analysis to establish the combined stress levels because of temperature, max boost loads, and acoustic energy absorption.	1. Lab testing of prototype structural components.
S-5	Ability to adequately vent module insulation without damage.	1. Design analysis to determine the optimum venting technique for module multilayer insulation.	1. Lab testing of prototype structural components.
S-6	Transmissibility of acoustic energy to subsystem equipment.	1. Conduct a dynamic analysis to establish the degree of transmissibility (or attenuation) which can be expected at the equipment mounting points.	1. Lab testing of prototype structural components.
S-7	Sensitivity to high G oscillatory vibrations along the X-axis.	1. Conduct a dynamic analysis which combines module, orbiter, and booster flight modal characteristics, to determine the gross flight vehicle vibration characteristics, especially in the longitudinal mode.	1. Dynamic testing of a representative module with simulated equipment installed.
S-8	Ability of multilayer insulation to withstand acoustics, vibration, and acceleration loads.	1. Conduct a design analysis to establish best method of supporting/ restricting multilayer insulation during the dynamic boost environment.	1. Lab testing of prototype structural components.
S-9	Air-tightness of pressure shell.	1. Design analysis of pressure shell to apportion leakage rates for all pressure shell penetrations, airlocks, and berthing ports.	1. Module Design Review.
S-10	Ability to clean/replace windows without EVA.	1. Conduct a design analysis to determine the optimum method of cleaning or replacing windows.	1. Module Design Freeze.
S-11	Adequacy of micrometeoroid protection of modules.	1. Conduct an analysis, based on statistical distribution of micrometeoroid mass and velocity, to predict the probability of impact and size of bumper required.	1. Module Design Review.
S-13	Ability of module structure to limit radiation dosage to the prescribed limits.	1. Conduct an analysis, based on the measured intensity of nuclear radiation from solar storms, normal galactic, etc., to determine the dosage rate to be expected.	1. Module Design Freeze.
S-14	Ability to operate the airlock and flexports successfully in terms of access, pressurization, and depressurization.	1. Design study to determine optimum configuration of airlock, considering all the human engineering requirements (reach, display, etc.). 2. Conduct a human engineering analysis to verify the adequacy of airlock hardware geometry in terms of accessibility to controls and equipment.	1. Module Design Review. 2. Module Design Freeze.

Table 2-15. Analysis Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
S-15	Minimize thermal energy gain/loss through module structure.	1. Thermodynamic analysis to determine the requirements for insulation, thermal control coating and to identify the major heat shorts. Establish a thermal math model for evaluation purposes.	1. Module Design Freeze.
S-16	Ability of the core module internal bulkheads to sustain maximum delta-P in either direction.	1. Structural analysis to determine limit and ultimate loads for internal bulkheads. Establish design margins.	1. Module Design Freeze.
S-17	Condensation on windows.	1. Design study to determine optimum arrangement of windows and adjacent structure to preclude condensation from forming on internal surfaces.	1. Module Design Freeze.
S-18	Ability of module structure to retard propagation of localized damage.	1. Conduct a design analysis to determine the optimum method/configuration for containing localized damage.	1. Module 100% Drawing Release.
S-19	Ability to deploy flexports between modules.	1. Conduct a design analysis to establish best way to keep flexports insensitive to non-parallelity of modules.	1. Module 100% Drawing Release.
S-20	Ability of flexports to withstand micrometeoroids.	1. Conduct an analysis, based on statistical distribution of micrometeoroid mass and velocity, to predict the probability of impact and size of bumper required.	1. Module 100% Drawing Release.
B-1	Functional compatibility of electrical and fluid interfaces across the berthed interface.	1. Conduct a design analysis to establish the physical design, location, and tolerances of the "standard" interface. Establish preliminary values of all operational parameters.	1. Berthing Design Freeze.
B-2	Structural integrity of berthing mechanism during berthing maneuvers.	1. Structural analysis to size the individual berthing components, considering the lack of impact attenuation.	1. Berthing Design Freeze.
B-3	Ability to open and close berthing hatches from either direction.	1. Human engineering analysis to determine the adequacy of hardware geometry in terms of accessibility to a suited crewman.	1. Berthing Design Review.
B-4	Compatibility of berthing interface when one module berthing port is at either temperature extreme and the other berthing port has been subjected to the shuttle bay temperature gradient.	1. Conduct a thermal analysis which will enable a berthing configuration to be selected such that it will be compatible with the expected temperature extremes and gradients.	1. Berthing Design Freeze.
B-5	Ability of berthing mechanism to operate properly after prolonged exposure to space environments.	1. Perform a design analysis to determine the materials, tolerances and lubrication requirements of all moving parts, considering the applied loads, hard vacuum, radiation, and temperature extremes.	1. Berthing Design Freeze.
B-6	Opening and closing of berthing, flexport, and airlock hatches after combined environments of low temperature, high humidity, and 3.1 psia PPO_2.	1. Conduct a thermodynamic analysis to determine possible location and kinds of icing. Recommend design to preclude possible icing.	1. Berthing Design Freeze.

Table 2-15. Analysis Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
B-7	Ability of shuttle and modules to deberth without damage to any of the bodies.	1. Perform an analysis of the separation dynamics, utilizing a math model approach, to determine miss distances for various separation modes.	1. Berthing Design Review.
B-8	Ability of the berthing mechanism to operate properly at the boundary extremes of the berthing envelope.	1. Perform an analysis of the berthing dynamics, utilizing a math model approach, to determine the boundary extremes of the berthing envelope.	1. Berthing Design Review.
B-9	Ability to open and close berthing port environmental protective covers.	1. Conduct a design analysis to establish the kinematics associated with opening and closing the berthing port environmental protective covers.	1. Berthing Design Freeze.
B-10	Ability of berthing interface seals to function through all thermal ranges.	1. Conduct a thermal analysis to determine the expected temperature extremes and temperature distribution expected at the interface seals.	1. Berthing Design Review.
B-11	Ability of berthing mechanism to disconnect remotely for return to earth.	1. Conduct a design analysis to establish method of positively releasing both halves of the berthed interface, prior to return to earth.	1. Berthing Design Review.
B-12	Ability to connect and disconnect utility lines across the berthed interface.	1. Perform detailed design and analysis to include gas collectors around hazardous lines across the berthed interface. Gas collectors must be flexible enough for suited crewmen to manipulate (in an emergency).	1. Berthing Design Freeze.
G-1	Mechanization of the G&C control modes.	1. Conduct trade studies to resolve such items as star tracking (gimballed optics) vs star mapping, all optical sensing modes vs optical/inertial sensing modes for attitude, references, etc.	1. G&C Design Freeze.
G-2	Development of optical reference and inertial reference preprocessor software.	1. Perform a subsystem analysis to establish the various subroutines for each of the required functions. 2. Establish and accumulate data from a ground-type computer program to evaluate the suitability of the preliminary software to interface properly with the ISS computer and all G&C sensors.	1. G&C Design Freeze. 2. Lab tests of prototype preprocessor and software.
G-3	Development of inflight maintenance concepts.	1. Conduct human engineering analysis to evaluate various ways and means to replace critical components and assemblies.	1. G&C 100% Drawing Release.
G-4	Determine optimum CMG control laws.	1. Conduct subsystem analysis to determine the most promising configuration of CMGs considering the most efficient momentum management.	1. G&C Design Freeze.
G-5	Accessibility of G&C equipment for installation, inspection,	1. Conduct a space analysis to determine clearance and tolerances of G&C equipment for adequate access.	1. G&C 100% Drawing Release.
G-6	Development of G&C checkout procedures.	2. Perform a subsystem analysis to establish the number and location of stimuli and test points, together with the tolerances of each measurement	2. G&C 100% Drawing Release.

Table 2-15. Analysis Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
G-9	Alignment of optical and inertial devices.	1. Conduct a design analysis to evaluate various techniques for mounting and aligning body sensors. Select the simplest and most accurate technique.	1. G&C 100% Drawing Release.
G-10	Optimize CMG control-loop performance.	1. Establish and obtain data from a ground-type computer program which simulates the performance of each function in the CMG control loop. Determine the effects of non-linearities.	1. G&C 100% Drawing Release
G-11	Ability of the G&C to operate within specified limits after exposure to the dynamic boost environment.	1. Conduct a design analysis to size G&C components and their mounting provisions for the expected dynamic boost environment.	1. G&C 100% Drawing Release.
G-12	Determination of outer-loop dynamics.	1. Conduct a dynamic analysis to determine the lateral bending modes, and torsional modes of the space station modular configuration. 2. Establish and obtain data from a computer program which combines the dynamic response characteristics of each module with the basic frequency response characteristics of the core module. Evaluate the transfer functions required for each different configuration of MSS.	1. G&C 100% Drawing Release.
G-13	Determination of rate damping and attitude-control gains.	1. Conduct trade-off studies to determine the degree of control required considering RCS propellant used. Determine suitable rate damping, attitude deadband, and gain settings for experiment support and manual docking control (emergency mode).	1. G&C 100% Drawing Release.
G-14	Determination of heat-sensitive components and assemblies.	1. Conduct a subsystem thermo-dynamic analysis to establish the maximum temperature limits for all G&C equipment which requires cooling.	1. G&C 100% Drawing Release.
G-15	Development of techniques for CMG	1. Conduct an analysis to size the RCS engines and CMGs such that their torques are matched. Establish preliminary procedures for desaturating the CMGs.	1. Start of scale-model CMG tests
G-16	Ability to detect G&C electro-mechanical failures and provide warning.	1. Conduct subsystem analysis to evaluate the performance/tolerance characteristics of all electro-mechanical features. Establish maximum/minimum tolerance for each IFRU. 2. Establish and obtain data from a computer program which will simulate G&C subsystem performance for all maximum/minimum limits and out-of-tolerance conditions.	1. G&C 100% Drawing Release. 2. G&C assembly tests in conjunction with DPA/C&D breadboard.
G-17	Updating of inertial measurement assembly.	1. Conduct a design analysis of the inertial measurement components to estimate the drift rate of IMU.	1. G&C 100% Drawing Release.

Table 2-15. Analysis Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
G-18	Servo-transfer functions for manual berthing (emergency mode).	1. Conduct a subsystem analysis to establish the servo-transfer function for the manual berthing operation (emergency mode). 2. Conduct human engineering analysis of the hand controllers used for manual berthing.	1. G&C 100% Drawing Release. 2. G&C 100% Drawing Release.
G-19	Ability of interim stabilization subsystem to stabilize initial modules.	1. Conduct a subsystem analysis of the interim control modes to establish subsystem requirements. Cover all configurations.	1. G&C 100% Drawing Release.
P-1	Compatibility of inverters with dedicated processors.	1. Conduct a system analysis to establish the inverter power module switching logic and computer word format.	1. EPS Design Freeze.
P-2	Development of power distribution system (PDS) checkout procedures.	1. Conduct a system analysis to determine the key operating parameters of the PDS for inclusion in the checkout procedure and checkout subroutine.	1. PDS breadboard tests.
P-3	Development of power conditioning system (PCS) checkout procedures.	1. Conduct a system analysis to determine the key operating parameters of the PCS for inclusion in the checkout procedures and checkout subroutine.	1. PCS breadboard tests.
P-4	Functional compatibility of EPS with other subsystems, GSE, and facility interfaces.	1. Conduct a system performance analysis to identify and define all the functional interfaces of the EPS (loads, OBCO, C&D, temperature control, etc.).	1. EPS Design Freeze.
P-5	Accessibility of EPS equipment and components for installation, inspection, and maintenance.	1. Conduct a space analysis to determine clearances and tolerances required for good accessibility to EPS equipment.	1. EPS Design Freeze.
P-6	Electromagnetic compatibility of EPS with other subsystems, GSE, and facility interfaces.	1. Perform an analysis of all local magnetic field-producing equipment and associated wiring. Investigate and establish the need for specific filters and shielding.	1. EPS Design Freeze.
P-7	Optimization of EPS to the normal and maximum electrical load profiles.	1. Conduct an analysis to construct detailed representative load profiles for various design missions. Establish total EPS capacity.	1. EPS Design Freeze.
P-9	Ability of energy storage device to meet peak demands.	1. Conduct a transient analysis of all modular space station electrical loads to establish the total capacity of the secondary storage device.	1. EPS Design Freeze.
P-10	Compatibility of solid-state circuit breakers with ISS computer.	1. Conduct a design analysis to establish the basic ISS computer subroutine for computer control of electrical power.	1. EPS Design Freeze.
P-11	Structural integrity of EPS subassemblies/assemblies during boost environment.	1. Perform a structural analysis of all EPS subassemblies and assemblies to establish safety margins for the dynamic boost environment.	1. EPS Design Freeze.

Table 2-15. Analysis Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
P-12	Overheating of wire bundles.	1. Conduct a thermal analysis to establish the total heat rejection load. Also, establish and optimize the prime method of heat rejection. Size method for vacuum operation.	1. EPS Design Freeze
P-13	Adequacy of protective circuitry to prevent propagation of component failures.	1. Perform a systems analysis of the complete EPS to determine all the possible component failure modes and the resultant optimum sensing and control circuit design which is required to prevent propagation.	1. EPS Design Freeze.
P-14	Compatibility of EPS with all MSS loads.	1. Perform a system analysis to establish the assymetrical pulse pattern and the ISS computer word format required to achieve minimum harmonics.	1. EPS Design Freeze.
P-15	Verification of fault detection circuits.	1. Conduct a design analysis to establish and incorporate fault detection circuits which are normally dormant but utilize a stimulus to verify that the circuit is operative.	1. EPS Design Freeze.
P-16	Excessive noise produced by magnetic hardware.	1. Perform an analysis of all inverter noise sources. Determine the best means of attenuating each source.	1. EPS Design Freeze.
P-17	Ability to synchronize AC units operating in parallel.	1. Conduct a systems analysis to establish the best means of keeping the AC units in synchronization, utilizing the CTE pulse.	1. EPS Design Freeze.
P-19	Ability of fuel cells and energy storage combination to meet emergency loads.	1. Conduct a systems analysis to determine worst case emergency load. Establish sensing and transfer techniques between solar array energy conversion and other power generation sources.	1. EPS Design Freeze.
A-1	Development of solar array (SA) checkout procedures.	1. Conduct a system analysis to determine the key operating parameters and establish the key test points.	1. SA Design Freeze.
A-2	Ability to handle, install, and align solar arrays.	1. Conduct a system analysis to provide the capability for handling and installing the SA.	1. SA Design Freeze.
A-3	Ability of all SA components and subassemblies to operate properly after exposure to the dynamic boost environment.	1. Conduct a structural analysis to size the orientation mechanism components and subassemblies for dynamic loads. Establish design margins.	1. SA Design Freeze.
A-4	Ability to deploy and retract solar arrays.	1. Conduct a design analysis to determine the best arrangement of parts and assemblies for simplicity of operation and high reliability. Select components for high reliability.	1. SA Design Freeze.
A-5	Ability of solar arrays to successfully withstand repeated deployment and retraction.	1. Conduct a design analysis to determine the best arrangement of strip assembly interconnections for long-life (repeated) operations.	1. SA Design Freeze.
A-6	Ability of power-transfer device to withstand continuous SA orientation motions.	1. Conduct a design analysis to determine the best configuration of the power transfer device to meet all operating conditions. Establish interface.	1. SA Design Freeze.

Table 2-15. Analysis Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
A-7	Ability to position solar arrays within prescribed sun line tolerance and response time.	1. Conduct a system analysis to determine the closed-loop sun angle tolerance and response characteristics.	1. SA Design Freeze.
A-8	RCS plume effects on solar cell performance.	1. Conduct an analysis of RCS plume composition and pattern to evaluate possible heating, surface degradation, and pressure effects which could reduce the performance characteristics of the solar arrays.	1. SA Design Freeze.
A-9	Ability to maneuver solar arrays in all required positions without shadowing or other adverse effects.	1. Conduct a computer orientation study (using 3 dimensional math representation) to identify and assess worst case conditions for positioning the solar arrays.	1. SA Design Freeze.
A-10	Ability to reposition solar arrays during earth shadow transit.	1. Conduct a design analysis to determine worst case requirements for orientation mechanism rate of repositioning.	1. SA Design Freeze.
A-11	Ability of orientation mechanism to operate properly after prolonged exposure to earth orbital environments.	1. Conduct a thermal analysis of the orientation mechanism to determine clearances and tolerances of all moving parts. Consider hard vacuum, temperature extremes, and temperature cycling conditions expected for MSS operations.	1. SA 100% Drawing Release.
A-12	Dynamic coupling of SA with MSS control system.	1. Establish a dynamic analysis computer program which will determine the sensitivity of SA structural/rigging designs to the fundamental resonances.	1. SA Design Freeze.
A-13	Effects of folding up a hot solar array.	1. Conduct a thermal analysis to assess the effects of folding up a hot solar array.	1. SA Design Freeze.
A-14	Effect of thermal cycling on solar array performance.	1. Conduct a thermal analysis to determine the relative motion between cell and bus parts because of different thermal coefficients of the materials. Match the relative motion between parts.	1. SA 100% Drawing Release.
A-15	Effect of SA reflectance on other MSS functions.	1. Conduct a computer orientation study (using 3 dimensional math representation) to identify and assess those positions of the solar array where reflectance will effect horizon sensors (or other MSS functions).	1. SA Design Freeze.
A-16	Development of "on-array" switching circuits.	1. Conduct a system analysis to determine switching circuit logic, max loads, and interface requirements.	1. SA Design Freeze.

Table 2-15. Analysis Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
I-1	Development of data-processing assembly (DPA) self-check capability.	1. Conduct a subsystem analysis to establish key operating parameters/subroutines which will indicate satisfactory DPA performance (a self-check).	1. ISS 100% Drawing Release.
I-2	Accessibility of ISS equipment for installation, inspection, maintenance, and repair.	1. Conduct a space allocation study to determine clearances and tolerances for all assemblies of the ISS (IFRUs).	1. ISS 100% Drawing Release.
I-3	Functional compatibility of ISS with interfacing subsystems, GSE, and facility interfaces.	1. Conduct a subsystem analysis to establish all functional interface parameters and special (environmental) characteristics for the ISS.	1. ISS 100% Drawing Release.
I-4	Electromagnetic compatibility of ISS with other subsystems, Shuttle, GSE, and facility interfaces.	1. Conduct an analysis to determine the location of electromagnetic field-producing equipment and associated wiring. Determine possible requirements for filters and shielding.	1. ISS 100% Drawing Release.
I-6	Determination of antenna radiation patterns.	1. Conduct a design analysis to predict antenna patterns. Also conduct trade studies to select the best space station for antennas. Estimate Voltage/Standing Wave Ratio (VSWR).	1. ISS 100% Drawing Release.
I-7	Adequacy of internal communications.	1. Conduct a subsystem analysis to establish the interface requirements for each functional unit.	1. ISS 100% Drawing Release.
I-8	Integration of all OBCO routines.	1. Conduct a subsystem analysis to establish a common format for all subsystem subroutines. Include results of analysis in Computer Program Contract End Item (CPCEI).	1. ISS 100% Drawing Release.
I-9	Ability of ISS to control EPS in all operational modes.	1. Conduct a subsystem analysis to establish all interface parameters and any special characteristics between the ISS and the EPS.	1. ISS 100% Drawing Release.
I-10	Ability of ISS equipment to operate properly after exposure to the dynamic boost environment.	1. Conduct a design analysis to determine the type and kind of dynamic isolation technique as well as the structural integrity requirements.	1. ISS 100% Drawing Release.
I-12	Determination of most suitable method for compensating for misalignment of high-gain antenna.	1. Conduct trade studies to determine the most suitable technique for measuring and compensating for the variable misalignment between antenna and MSS axes.	1. ISS 100% Drawing Release.
I-13	Ability of high-gain antenna to operate properly after prolonged exposure to earth-orbital environments.	1. Conduct a thermal analysis of the antenna assembly to determine the clearances and tolerances of all moving parts and the amount of force required to move antenna at the environmental extremes.	1. ISS 100% Drawing Release.
I-14	Compatibility of both real-time and recorded data playback with telemetry ground stations for high data rate and video fidelity.	1. Conduct a subsystem analysis to establish all interface requirements (ICDs) and identify possible areas of incompatibility.	1. ISS 100% Drawing Release.
I-15	Performance of RF communications within circuit performance margins and expected ranges.	1. Calculate circuit performance margins for all communication links to determine the maximum usable range of each link.	1. ISS 100% Drawing Release.

Table 2-15. Analysis Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
I-16	Ability of OBCO to effectively sample and compare IFRU data to trend data.	1. Conduct a subsystem analysis to establish the basic computer format (language) to be used for storing each IFRU signature. Incorporate in CPCEI.	1. ISS 100% Drawing Release.
I-17	Optimization of all displays and controls.	1. Conduct a subsystem analysis to establish common requirements for all displayed information. Include man-in-loop studies.	1. ISS 100% Drawing Release.
I-18	Development of efficient techniques for implementing real-time executive control of computer complex.	1. Conduct a subsystem analysis to establish a definitive specification and a specification tree for all software requirements. Incorporate results in CPCEI.	1. ISS 100% Drawing Release.
I-19	Development of effective scheduling of DPA.	1. Conduct a detailed mission analysis to determine the optimum "data load" which can be handled by the data processing assembly.	1. ISS 100% Drawing Release.
I-20	Development of computer routines for effective mission planning and mission management.	1. Establish computer routines for all required functions which are necessary to accomplish mission planning and mission management (consumables on-board, personnel, etc.).	1. ISS 100% Drawing Release.
I-21	Mechanization of semi-omni directional switching.	1. Conduct trade studies to evaluate various methods of antenna switching techniques (strongest signal, space station logic, etc.).	1. ISS Design Freeze.
I-23	Development of central processor traffic flow control technique.	1. Conduct a design analysis to establish circuitry concept that will handle 10^7 BPS digital data flow rate.	1. ISS Design Freeze.
I-24	Development of interactive (English-language) vocabulary for software mods and crew control of computer.	1. Establish computer word and data word for the basic computer program based on an English-language approach.	1. ISS 100% Drawing Release.
I-25	Development of high-density digital storage device.	1. Conduct a design analysis to determine all requirements. Document requirements in a procurement specification.	1. ISS 100% Drawing Release.
I-26	Elimination of noise on the data bus.	1. Conduct a subsystem analysis to determine the best way to shield the data bus from external noise sources. Also, determine noise-immune transfer forms and component design concepts which will be immune to noise.	1. ISS 100% Drawing Release.
I-27	Ability of ISS to control all functions of the ECLSS.	1. Conduct a subsystem analysis to establish all parameters of the functional interface as well as special characteristics involved in the design solution. Document by ICDs.	1. ISS 100% Drawing Release.
I-28	Develop the functional and design interface between the DPA and the UTE.	1. Conduct a subsystem analysis to establish the functional interface and performance characteristics of each side of the interface.	1. ISS 100% Drawing Release.

Table 2-15. Analysis Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
I-29	Establish the data format to be used for stored trend data.	1. Conduct a subsystem analysis to establish the concept of statusing subsystems performance, compare with stored trend data, and generate commands and displays to the crew. Define data format.	1. ISS 100% Drawing Release.
I-30	Ability to transfer command/ control functions.	1. Conduct a subsystems analysis to select the most desirable manner of transferring the control functions. Establish requirements, sequence of operations, and tasks.	1. ISS 100% Drawing Release.
I-31	Ability of ISS to control all functions of the G&C.	1. Conduct a subsystem analysis to establish all parameters of the functional interface as well as special characteristics involved in the design solution. Document by ICDs.	1. ISS 100% Drawing Release.

Table 2-16. Mockup Subprogram

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
R-1	Functional compatibility of RCS with other subsystems, GSE, and facility interfaces.	1. Conduct tests to establish clearances and tolerances for all physical interfaces in the "as installed" configuration.	1. RCS 100% Drawing Release.
R-4	Accessibility of RCS equipment and components for installation, inspection, test, and maintenance.	1. Conduct tests with simulated RCS equipment to evaluate accessibility for replacing IFRUs and for general maintenance and inspection.	1. RCS 100% Drawing Release.
H-2	Determination of the optimum habitability criteria.	1. Conduct tests with potential crewmen which will evaluate the MSS criteria for habitability in all work, rest, and recreation areas.	1. Habitability 100% Drawing Release.
H-5	Ability of crew to perform all man-machine tasks.	1. Conduct tests which will evaluate the man-machine relationships during performance of some crew tasks.	1. Finalization of crew selection and training criteria.
H-6	Interface compatibility of government furnished equipment (GFE) with the MSS.	1. Conduct tests which will evaluate the interface compatibility of the GFE with simulated space station equipment and stowage areas.	1. Habitability 100% Drawing Release.
H-7	Adequacy of crew accessories and restraint devices.	1. Conduct tests to determine that the tools and aids/restraints are functional and that storage is adequate for each item.	1. Habitability 100% Drawing Release.
H-8	Adequacy of internal lighting.	1. Conduct tests which will evaluate the adequacy of the internal lighting for the function intended (work, rest, recreation areas).	1. EPS 100% Drawing Release.
H-9	Ability to transfer cargo between shuttle and modules, and between floors.	1. Conduct tests, with simulated cargo, to evaluate accessibility to cargo transfer equipment and evaluate the preliminary cargo handling procedures.	1. Final criteria for cargo transfer equipment and final crew procedures for cargo handling.
H-10	Adequacy of tie-down arrangements to secure cargo and all loose equipment.	1. Conduct tests, with simulated cargo and loose equipment, to evaluate the adequacy of the tie-down arrangements.	1. Final criteria for equipment tie-down arrangements.
H-11	Ability of suited crewman to open and close any hatch in zero-g.	1. Conduct tests which will evaluate clearances and accessibility to all hatches and the airlock controls.	1. Final criteria for all hatch operation and airlock control arrangements.
H-12	Ability of suited crewman to make/remove berthed interface connections.	1. Conduct tests which will evaluate clearances and accessibility to all berthed interface connections.	1. Module 100% Drawing Release.
E-2	Accessibility of ECLSS equipment for installation, inspection, maintenance, and repair.	1. Conduct tests which will evaluate the accessibility of simulated equipment for installation and replacing IFRU's, general maintenance and inspection operations.	1. Installation of prototype subsystems into representative module.
E-3	Functional compatibility of ECLSS with interfacing subsystems, GSE, and facility interfaces.	1. Conduct tests to verify the clearances and tolerances for all the physical interfaces.	1. ECLSS 100% Drawing Release.
E-19	Balance subsystem for proper airflow in each module.	1. Conduct smoke tests, with air ducts, diffusers, registers, and circulation fans installed, to determine flow interruptions and stagnant areas.	1. ECLSS 100% Drawing Release.

Table 2-16. Mockup Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
S-1	Accessibliity to interior pressure walls for inspection, maintenance, and repair.	1. Verify clearances and general accessibility to interior pressure walls for inspection, maintenance, and repair.	1. Module 100% Drawing Release.
S-10	Ability to clean/replace windows without EVA.	1. Verify adequacy of window concept by conducting demonstrations of clean/replace technique. Establish procedures.	1. Module 100% Drawing Release.
S-14	Ability to operate the airlock and flexports successfully in terms of access, pressurization, and depressurization.	1. Conduct evaluation of airlock controls and equipment to determine ease of operation in a one-g no-constraint environment. Evaluate design for adequacy of manual operation. Recommend improvements.	1. Module 100% Drawing Release.
S-19	Ability to deploy flexports between modules.	1. Conduct tests between two adjacent modules to evaluate ability of flexport to satisfactorily mate with the target port. Non-parallel surfaces, misalignment of center lines, installation tolerance extremes to be incorporated in test items as practical.	1. Module 100% Drawing Release.
B-1	Functional compatibility of electrical and fluid interfaces across the berthed interface.	1. Evaluate the soft mockup of the berthed interface for accessibility for leak checking, repair/replace, and inspection activities.	1. Berthing 100% Drawing Release.
B-3	Ability to open and close berthing hatches from either direction.	1. Determine operability of the berthing hatches (in a one-g environment) considering human engineering criteria and crew aids. Evaluate adequacy of the design concept for manual operation in a zero-g environment.	1. Berthing 100% Drawing Release.
B-9	Ability to open and close berthing port environmental protective covers.	1. Conduct tests on soft mockup of the berthing ports to determine the operability of the environmental protective covers.	1. Lab tests of prototype berthing subsystem.
B-12	Ability to connect and disconnect utility lines across the berthed interface.	1. Conduct tests with simulated/prototype gas collector installation to determine operability of disconnects and lines by a suited crewman.	1. Lab tests of prototype gas collectors/disconnects.
G-5	Accessibility of G&C equipment for installation, inspection, maintenance, and repair.	1. Conduct tests with simulated G&C components and assemblies to evaluate the accessibility for installing and replacing IFRUs and for general inspection and maintenance.	1. G&C 100% Drawing Release.
G-7	Functional compatibility of G&C with interfacing subsystems, GSE, and facility interfaces.	1. Conduct tests with simulated G&C components and assemblies to establish installation fits and clearances for all physical interfaces.	1. Installation of prototype G&C components into representative module.

Table 2-16. Mockup Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
P-5	Accessibility of EPS equipment and components for installation, inspection, maintenance, and repair.	1. Conduct tests to evaluate the general accessibility of EPS equipment for replacement and routine inspection/maintenance.	1. EPS 100% Drawing Release.
P-12	Overheating of wire bundles.	1. Perform tests to determine the best configuration of the cooling method chosen for each particular wire bundle.	1. Start of PDS breadboard tests in vacuum chamber.
A-2	Ability to handle, install, and align solar array.	1. Conduct tests to evaluate the ability to handle, install and align (with ISS C&D) the solar arrays on the power module.	1. Installation of prototype subsystems into representative module.
I-2	Accessibility of ISS equipment for installation, inspection, maintenance, and repair.	1. Conduct tests which will evaluate the accessibility of all ISS equipment for installation, inspection, maintenance, and repair.	1. ISS 100% Drawing Release.
I-17	Optimization of all displays and controls.	1. Conduct tests to evaluate the size, placement, grouping, illumination, and readability of all displays. Evaluate location of all controls.	1. Fabrication of prototype control console.

Table 2-17. Zero-G Simulation Subprogram

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
H-1	Selection, qualification, and training of crewmen.	1. Conduct tests, with human subjects in a 6 DOF task analysis simulator, to establish the metabolic cost of doing some major tasks.	1. Finalization of crew selection and training criteria.
H-5	Ability of crew to perform all man-machine tasks.	1. Conduct tests in a KC-135, with suitable mockups, to evaluate man's ability to perform certain tasks in a zero-g environment.	1. Habitability 100% Drawing Release.
H-6	Interface compatibility of government furnished equipment (GFE) with the MSS.	1. Conduct tests in a neutral buoyant facility which will evaluate interface compatibility between crewmen in a PGA (with PLSS) and simulated berthing hatches, airlock, and airlock hatches.	1. Module 100% Drawing Release.
H-7	Adequacy of crew accessories and restraint devices.	1. Conduct tests in a neutral buoyant facility which will verify that crewmen can manipulate tools and that aids/restraints are adequate for the task.	1. Habitability 100% Drawing Release.
H-9	Ability to transfer cargo between shuttle, modules, and between module floors.	1. Conduct tests in a neutral buoyant facility with simulated berthing port and cargo transfer equipment, to evaluate cargo handling procedures, crew restraint devices/ aids, etc.	1. Module 100% Drawing Release.
H-10	Adequacy of tie-down arrangements to secure cargo and all loose equipment.	1. Conduct tests in a neutral buoyant facility, with simulated cargo and loose equipment, to evaluate the adequacy of tie-down arrangements for zero-g operations.	1. Habitability 100% Drawing Release.
H-11	Ability of suited crewmen to open and close any hatch in zero-g.	1. Conduct tests in a neutral buoyant facility with hard mockup of berthing port, airlock, to evaluate the difficulty of opening and closing any hatch or control.	1. Module 100% Drawing Release.
H-12	Ability of suited crewman to make/remove interface connections (emergency mode).	1. Conduct tests in a neutral buoyant facility, with hard mockup of berthing port and hatches, to evaluate the difficulty in connecting/ disconnecting the interface connections.	1. Module 100% Drawing Release.
B-3	Ability to open and close berthing hatches from either direction.	1. Conduct neutrally buoyant tests with a hard mockup of the berthed interface. Evaluate crew procedures and crew restraint equipment in this simulated zero gravity environment. Recommend changes.	1. Fabrication of flight-type berthing assembly.
B-7	Ability of shuttle and modules to de-berth without damage to any of the bodies.	1. Conduct tests of air-levitated scale models to evaluate motion of the bodies during separation 2. Conduct tests on an engineering simulator, utilizing prototype berthing subsystem (both halves), with a computer program which simulates the MSS and shuttle dynamic characteristics. Determine the ability to de-berth without damage to either body. Duplicate all configurations of the MSS for this task.	1. Start of simulated deberthing tests on 6 DOF engineering simulator. 2. Fabrication of flight-type berthing assembly.

Table 2-17. Zero-G Simulation Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
B-8	Ability of the berthing mechanism to operate properly at the boundary extremes of the berthing envelope.	1. Conduct tests of air-levitated scale models to evaluate performance of the berthing mechanism at the boundary extremes of the berthing envelope. 2. Conduct simulated berthing tests in an engineering simulator (6 DOF), with a computer program which simulates MSS dynamic characteristics, to assess the performance of the berthing mechanism at the boundary extremes of the berthing envelope.	1. Start of simulated berthing tests on 6 DOF engineering simulator. 2. Fabrication of flight-type berthing assembly.
G-13	Determination of rate damping and attitude-control gains.	1. Conduct tests on an engineering simulator, utilizing prototype G&C equipment, with a computer program which simulates the MSS outer-loop dynamics. Determine the optimum damping, attitude deadbands, and gain settings for all modes of possible operation.	1. Installation of subsystems into first flight module.
G-18	Servo-transfer functions for manual berthing (emergency mode).	1. Conduct berthing simulation tests with prototype G&C hardware (including hand controllers) to verify suitability of the servo-transfer functions.	1. Installation of subsystems into first flight module.

Table 2-18. Engineering Test Laboratory Subprogram

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
R-1	Functional compatibility of RCS with other subsystems, GSE, and facility interfaces.	1. Conduct tests with RCS breadboard, CPA/C&D breadboard, to establish compatibility with GSE, preprocessor, local processors, etc.	1. Start of combined subsystems tests in representative module.
R-2	Electromagnetic compatibility of RCS with interfacing subsystems.	1. Perform tests on all RCS electromechanical components to evaluate compliance with EMC requirements. 2. Conduct tests with RCS breadboard, DPA/C&D breadboard, to determine electromagnetic compatibility with interfacing subsystems.	1. Start of RCS breadboard and DPA/C&D breadboard combined tests. 2. Start of combined subsystems tests in representative module.
R-3	Development of RCS checkout procedures.	1. Conduct tests on RCS breadboard, to evaluate preliminary RCS checkout routine.	1. Start of combined subsystems tests in representative module.
R-5	Compatibility of seals and lubricants with the gaseous propellants.	1. Conduct tests on candidate materials for seals and lubricants to evaluate and select most suitable combinations for O_2 and H_2. 2. Conduct tests on RCS breadboard to determine the degree of compatibility of seals and lubricants at environmental extremes. 3. Conduct tests on RCS prototype subsystem which will demonstrate the compatibility of seals and lubricants.	1. RCS 100% Drawing Release. 2. Start of RCS prototype subsystem tests. 3. Installation of subsystems into first flight module.
R-6	Ability of RCS to operate properly after exposure to the boost environment.	1. Conduct tests on prototype RCS components to the full spectrum of boost environments to determine adequacy of design. 2. Subject flight-type RCS assembly to combined boost environments to verify the adequacy of the "as installed" design.	1. Start of RCS assembly tests to combined boost environments. 2. Installation of subsystems into first flight module.
R-7	Ability of RCS to operate properly after prolonged exposure to earth-orbital environments.	1. Conduct tests on prototype RCS components to evaluate the effects of environmental extremes and long-term exposure to space environments. 2. Subject a flight-type RCS assembly to environmental extremes for long-term testing (180 days). Operate all components to verify ability to withstand the effects of space.	1. Start of RCS assembly tests to environmental extremes. 2. Installation of subsystems into first flight module.
R-8	Effect of propellant temperatures, accumulator pressure variations, and mixture ratio extremes on RCS performance.	1. Conduct tests on prototype RCS components to determine the performance characteristics at the parametric extremes. 2. Subject a flight-type RCS assembly to the parametric extreme conditions; fire all engines to demonstrate the ability of the assembly to perform within spec limits at the parametric extremes.	1. Start of RCS assembly tests to parametric extreme conditions. 2. Installation of subsystems into first flight module.
R-9	Ability to meet minimum impulse requirements.	1. Conduct tests on prototype RCS propellant valves under fluid dynamic conditions to establish valve actuation characteristic. 2. Conduct altitude chamber tests with prototype RCS engines to determine minimum impulse. 3. Subject a flight-type RCS assembly to altitude conditions ($>$ 250K ft.); fire all engines to demonstrate minimum impulse with all subsystem dynamic characteristics.	1. Start of RCS engine tests at altitude. 2. Start of RCS assembly tests at altitude. 3. Installation of subsystems into first flight module.

Table 2-18. Engineering Test Laboratory Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
H-5	Ability of crew to perform man-machine tasks.	Conduct tests with DPA/C&D bread-board and control console to determine (partially) the suit-ability of man-machine relation-ships.	Start of combined subsystems tests in representative module.
E-1	Development of ECLSS checkout procedures.	Determine suitability of preli-minary checkout procedures during performance tests of prototype components and subassemblies.	Start of combined subsystems tests in representative module.
E-3	Functional compatibility of ECLSS with interfacing subsystems, GSE, and facility interfaces.	Conduct tests with all ECLSS prototype components, and simu-lated interfaces, to determine any areas of incompatibility.	Start of combined subsystems tests in representative module.
E-4	Electromagnetic compatibility of ECLSS with other subsystems, GSE, and facility interfaces.	Conduct tests with all ECLSS elec-trical/electromechanical devices to evaluate compliance with EMC requirements.	Start of combined subsystems tests in representative module.
E-5	Development of coldplate approach.	Conduct tests with prototype cold-plates and dummy IFRUs (for heat loads) to determine the suit-ability of the design for all the required mission modes.	Start of combined subsystems tests in representative module.
E-8	Ability of ECLSS to operate within specified limits after exposure to the dynamic boost environment.	Conduct dynamic tests on all proto-type ECLSS functional components to determine their ability to survive the dynamic boost environ-ment. Conduct dynamic tests on all flight-type ECLSS functional com-ponents to certify these compo-nents for the dynamic boost environment.	Fabrication of flight-type ECLSS components. Installation of subsystems into first flight module.
E-9	Ability of ECLSS to maintain water vapor (relative humidity) within tolerance.	Conduct tests with prototype humidity control heat exchanger to determine maximum capacity and operating characteristics.	Start of combined subsystems in representative module.
E-10	Ability of ECLSS to adequately remove CO_2, odors, debris, and contaminants.	Conduct tests with prototype hydro-gen depolarizer and catalytic oxidizer units to determine the ability to remove contaminants and toxic elements.	Start of combined subsystems tests in representative module.
E-11	Ability of ECLSS to maintain proper O_2/N_2 partial pressure relationship.	Conduct tests on prototype ECLSS partial pressure regulators to determine the ability to maintain proper relationship between O_2/N_2.	Start of combined subsystems tests in representative module.
E-12	Ability of ECLSS to maintain correct temperature at coldplate inlets.	Conduct tests on all prototype heat exchangers in the active thermal control loop to determine "in-out" temperatures. Compare data with thermal analysis.	Start of combined subsystems tests in representative module.
E-13	Ability of sterilization equip-ment to adequately control purity of water.	Conduct tests with prototype sterility control components to determine the ability to adequately control processed water purity.	Start of combined subsystems tests in representative module.
E-14	Ability of urine, condensate, wash water and waste water recovery circuits to adequately reclaim water.	Conduct tests with prototype vapor compression still and associated components (pump, conductivity sensor, etc.) to determine the ability to reclaim urine, conden-sate, wash water, and waste water.	Start of combined subsystems tests in representative module.

Table 2-18. Engineering Test Laboratory Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
E-15	Ability of water electrolysis unit to produce O_2/H_2 at the required rate.	Conduct tests with prototype electrolysis stacks to determine the gas production rate. Also simulate one cell "failed" and operate the others at higher current density.	Start of combined subsystems tests in representative module.
E-16	Ability of all condensers to extract water efficiently.	Conduct tests with all prototype condensing heat exchangers to determine the ability to extract all the H_2O collected.	Start of combined subsystems tests in representative module.
E-17	Ability to limit equipment noise to acceptable levels.	Conduct tests of prototype pumps, fans, and blowers to determine the noise level produced and methods of attenuation.	Start of combined subsystems tests in representative module.
E-19	Ability to remove and replace IFRUs without spillage or trapping air in liquid lines.	Conduct lab tests with prototype disconnects to determine the ability to prevent spills and trapping air in liquid lines.	Start of combined subsystems tests in representative module.
E-21	Degradation of thermal-control coating by RCS plume effects.	Conduct altitude chamber firings of RCS engines with coated panels placed in approximate orientation, to determine the degradation effects. Measure heat rejection capability before and after altitude chamber tests.	
E-22	Corrosion effects of the water management assembly.	Conduct lab tests with prototype Sabatier O_2 reduction unit, vapor compression still, and reverse osmosis to determine the probable areas where corrosion products may form. Inspect all units.	Start of combined subsystems tests in representative module.
E-23	Ability of pumpdown components to operate in time period allotted.	Conduct lab tests with prototype pumping components to determine the overall pumping capability and to establish operational characteristics of equipment.	Start of combined subsystems tests in representative
S-2	Effects of acoustics on structural integrity.	1. Subject structural test panels (2) to the predicted acoustic profile to determine transmissibility factors and attenuation characteristics.	1. Fabrication of first flight module.
S-3	Ability of module structure to sustain all loads imposed by attached equipment as a result of ground handling, checkout, boost, landing, emergency, etc.	1. Subject each representative structural component to limit and ultimate loads to evaluate structural integrity for each test condition.	1. Fabrication of first flight module.
S-4	Ability of modules to withstand effects of combined boost environment.	1. Subject prototype structural components to combined environments to determine stress levels and stress distribution pattern.	1. Fabrication of first flight module.
S-5	Ability to adequately vent module insulation without damage.	1. Subject (2) structural test panels to real-time ascent pressure profile. Determine adequacy of venting technique.	1. Fabrication of first flight module.
S-6	Transmissibility of acoustic energy to subsystem equipment.	1. Conduct acoustic tests on (2) structural test panels to verify transmissibility factors to the installed subsystem equipment.	1. Qualification tests of all subsystem equipment.

Table 2-18. Engineering Test Laboratory Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
S-8	Ability of insulation to withstand acoustics, vibration, and acceleration loads.	1. Subject (2) structural test panels (with insulation installed) to the boost dynamic environment to demonstrate the adequacy of insulation support technique.	1. Fabrication of first flight module.
S-9	Air-tightness of pressure shell.	1. Subject candidate seal and gasket material to high vacuum, maximum/minimum temperature cycling, and nuclear radiation. Select most suitable materials.	1. Module 100% Drawing Release.
S-10	Ability to clean/replace windows without EVA.	1. Subject prototype window assembly to functional tests which will determine the required operational capability.	1. Fabrication of first flight windcw assembly.
S-11	Adequacy of micrometeoroid protection of modules.	1. Subject micrometeoroid bumper sample materials, mounted on structural test panels, to hypervelocity particle bombardment. Evaluate ability to absorb particle energy. Recommend best bumper configuration.	1. Module 100% Drawing Release.
S-12	Selection of optimum method of repairing micrometeoroid damage.	1. Evaluate various sample materials and procedures for repairing a "standard" micrometeoroid puncture. Recommend best materials and methods.	1. Module 100% Drawing Release.
S-15	Minimize thermal energy gain/loss through module structure.	1. Conduct tests with sample thermal insulation and thermal control coatings to evaluate optimum combination. Measure absorbtivity and emissivity after long-term exposure to simulated space environments, including galactic radiation and micrometeoroid particle impingement. Measure heat flux and temperature gradients through structure.	1. Module 100% Drawing Release.
S-16	Ability of the core module internal bulkheads to sustain maximum delta-P in either direction.	1. Subject major structural joints and subassemblies to limit and ultimate loads based on maximum pressure differentials. Determine margins.	1. Fabrication of first flight module.
S-17	Condensation on windows.	1. Conduct thermal tests on flight-configured window assembly to determine overall thermal conductivity at worst operating conditions (conducive to producing condensation on windows).	1. Module 100% Drawing Release.
S-18	Ability of module structure to retard propagation of localized damage.	1. Conduct tests with structural test panels to demonstrate that localized damage will not propagate beyond the established boundaries.	1. Fabrication of first flight module.
S-19	Ability to deploy flexports between modules.	1. Subject prototype flexports and extension mechanisms to lab tests which will evaluate their operability.	1. Fabrication of flight-type flexports and extension mechanism.
S-20	Ability of flexports to withstand micrometeoroid impacts.	1. Subject sample bumper materials to hyper-velocity particle impingement to verify selected configuration of flexport.	1. Flexport 100% Drawing Release.

Table 2-18. Engineering Test Laboratory Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
B-1	Functional compatibility of electrical and fluid interfaces across the berthing interface.	1. Laboratory tests with prototype berthing assembly (both halves) to determine functional compatibility of electrical and fluid interfaces.	1. Start of combined subsystem tests with prototype berthing assembly.
B-2	Structural integrity of berthing mechanisms during berthing maneuvers.	1. Conduct laboratory tests with prototype berthing mechanism components to evaluate adequacy of the design to absorb closing impact loads. 2. Perform simulated berthing tests with prototype berthing assembly (each half attached to vertical test fixture) to determine ability of assembly to absorb closing impact loads.	1. Start of simulated berthing tests in lab. 2. Fabrication of flight-type berthing assembly.
B-4	Compatibility of berthing interface when module port is at either temperature extreme and module has been subjected to shuttle bay temperature gradient.	1. Conduct tests with prototype berthing mechanism components and subassemblies to evaluate the effects of temperature extremes. 2. Conduct thermal-vacuum tests of prototype berthing assembly when each half is at a different temperature extreme. Record force to engage, disengage, etc.	1. Environmental tests of prototype berthing assembly. 2. Fabrication of flight-type berthing assembly.
B-5	Ability of berthing mechanism to operate properly after properly after prolonged exposure to the space environment.	1. Conduct lab tests of prototype berthing mechanism components and subassemblies to evaluate effects of environmental extremes. 2. Conduct thermal-vacuum tests of prototype berthing assembly to determine the effects of prolonged exposure to simulated space environments.	1. Environmental tests of prototype berthing assembly. 2. Fabrication of flight-type berthing assembly.
B-9	Ability to open and close berthing port environmental protective covers.	1. Conduct tests of prototype berthing assembly, at temperature extremes, temperature gradients, and vacuum conditions to determine the ease of opening and closing the environmental protective covers.	1. Fabrication of flight-type berthing assembly.
B-10	Ability of berthing interface seals to function through all thermal ranges.	1. Subject candidate seals to high vacuum, maximum/minimum temperature cycling, and nuclear radiation. Select most suitable material. 2. Conduct tests of prototype berthing assembly at temperature extremes and temperature gradients, to determine ability of seals to function properly through all temperature ranges.	1. Berthing 100% Drawing Release. 2. Fabrication of flight-type berthing assembly.
B-11	Ability of berthing mechanism to disconnect remotely for return to earth.	1. Conduct laboratory tests of latch release mechanism to evaluate capability to disconnect remotely. 2. Determine ability of the berthing mechanism to disconnect remotely by tests conducted in thermal-vacuum environment, at simulated space conditions, after long-term storage at these conditions.	1. Environmental tests of prototype berthing assembly. 2. Fabrication of flight-type berthing assembly.
B-12	Ability to connect and disconnect utility lines across the berthing interface.	1. Conduct laboratory tests of prototype gas collectors and disconnects to determine the forces and tolerances required to connect and disconnect the utility lines.	1. Fabrication of flight-type gas collectors and disconnects.

Table 2-18. Engineering Test Laboratory Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
G-1	Mechanization of the G&C control modes.	1. Conduct tests of breadboard G&C components (functions) to determine ability of G&C to perform all control modes in an adequate manner. 2. Conduct tests of prototype G&C and DPA/C&D breadboard to demonstrate the ability of G&C to perform all control modes within specification limits.	1. G&C 100% Drawing Release.
G-2	Development of optical reference and inertial reference pre-processor software.	1. Conduct laboratory tests with prototype pre-processor and computer simulation of subsystem interfaces (all stimulus) to determine total capability of the software.	1. Start of combined subsystems tests in representative module.
G-3	Development of inflight maintenance concepts.	1. Conduct tests with prototype G&C equipment to determine the effect of preliminary maintenance procedures. Update procedures as required.	1. Fabrication of flight-type G&C equipment.
G-4	Determine optimum CMG control laws.	1. Conduct tests with scaled-down CMGs mounted on an air-bearing rig. Determine the effectiveness of the vehicle control laws produced by the CMGs to orient the MSS. 2. Conduct tests with prototype CMGs to demonstrate the response of the CMGs to simulated command moments. Computer simulation of MSS dynamics is required for these tests.	1. Start of prototype CMG tests. 2. Installation of subsystems into first flight modules.
G-6	Development of G&C checkout procedures.	1. Conduct tests with G&C breadboard and DPA/C&D breadboard to determine suitability of the preliminary checkout procedures.	1. Start of combined subsystems tests in representative module.
G-7	Functional compatibility of G&C with interfacing subsystems, GSE, and facility interfaces.	1. Conduct tests with G&C breadboard, with simulated interfaces, to determine compatibility of the G&C.	1. Start of combined subsystems tests in representative module.
G-8	Electromagnetic compatibility of G&C with interfacing subsystems.	1. Subject prototype G&C components to laboratory tests which will evaluate compliance with EMC requirements. 2. Subject prototype G&C subassemblies and assemblies to laboratory tests which will determine compliance with EMC requirements.	1. Start of prototype G&C subassembly and assembly tests. 2. Start of combined subsystems tests in representative module.
G-9	Alignment of optical and inertial devices.	1. Conduct tests with prototype mounting and alignment equipment to determine accuracy of method selected.	1. Start of combined subsystems tests in representative module.
G-10	Optimize CMG control loop performance.	1. Conduct tests with CMGs, mounted on an air-bearing rig, to determine the non-linear relationships established by the CMG computer program analysis.	1. Start of combined subsystems tests in representative module.
G-11	Ability of the G&C to operate within specified limits after exposure to the dynamic boost environment.	1. Conduct tests with prototype G&C components to determine structural and functional integrity to the dynamic boost environment. 2. Conduct tests with flight-type G&C assemblies to verify structural and functional integrity to the dynamic boost environment.	1. Fabrication of flight-type G&C assemblies. 2. Installation of subsystems into first flight module.

Table 2-18. Engineering Test Laboratory Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
G-13	Determination of rate damping and attitude-control gains.	1. Conduct tests with G&C breadboard to determine subsystem characteristics and the limits of rate damping and gains.	1. Start of 6 DOF Engineering simulator tests with prototype G&C equipment.
G-14	Determination of heat-sensitive components and assemblies.	1. Conduct tests with prototype G&C components mounted on prototype coldplate (with ground cooling cart) to determine the cooling characteristics of G&C equipment.	1. Fabrication of flight-type coldplates and G&C mounting provisions.
G-15	Development of technique for CMG desaturation with RCS.	1. Conduct tests with prototype CMGs, mounted on an air-bearing rig, to determine validity of procedures to desaturate CMGs using simulated external torque.	1. Fabrication of prototype CMGs.
G-16	Ability to detect G&C electromechanical failures and provide warning.	1. Conduct tests with prototype G&C assemblies and the DPA/C&D breadboard to demonstrate the ability to detect and provide a warning to the crew.	1. Start of combined subsystems tests in representative module.
G-17	Updating of inertial measurement assembly.	1. Conduct laboratory tests of IMU breadboard to determine the acceptability of the measured drift rate. 2. Conduct tests with prototype IMU to demonstrate the update capability utilizing simulated star sighting/earth landmark signals.	1. Start of prototype IMU tests. 2. Start of 6 DOF Engineering simulator tests with prototype
G-19	Ability of stabilization subsystem to stabilize initial modules.	1. Conduct tests with breadboard G&C components (functions) to determine functional capability with each internal configuration. 2. Conduct tests with prototype G&C equipment to demonstrate ability to control all interim configurations within spec limits.	1. Fabrication of prototype G&C equipment. 2. Start of combined subsystems tests in representative module.
P-1	Compatibility of inverters with dedicated processors.	1. Conduct tests of the PCS breadboard with processor-controlled inverters feeding simulated loads, to evaluate compatibility of the inverters.	1. Start of combined EPS breadboard tests.
P-2	Development of power distribution system (PDS) checkout procedures.	1. Conduct tests on PDS breadboard to evaluate preliminary checkout procedures.	1. Start of combined EPS breadboard tests.
P-3	Development of power conditioning system (PCS) checkout procedures.	1. Conduct tests on PCS breadboard to evaluate preliminary checkout procedures.	1. Start of combined EPS breadboard tests.
P-4	Functional compatibility of EPS with other subsystems, GSE, and facility interfaces.	1. Conduct tests of PDS and PCS, with simulated interfaces and full range of loads, to evaluate intersystem compatibility of EPS with other subsystems.	1. Start of combined subsystems tests with prototype EPS equipment.
P-6	Electromagnetic compatibility of EPS with other subsystems, GSE, and facility interfaces.	1. Conduct tests of prototype EPS components and/or subassemblies to evaluate the degree of compliance with EMC requirements.	1. Start of combined EPS breadboard tests.

Table 2-18. Engineering Test Laboratory Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
P-7	Optimization of EPS to the normal and maximum electrical load profiles.	1. Conduct tests with the PCS and PDS breadboards, with simulated loads, to evaluate EPS ability to handle all changes in the profile. 2. Conduct tests with EPS breadboard and DPA/C&D breadboard, with simulated electrical loads, to determine ability of EPS to handle normal, maximum, and emergency load profiles.	1. Start of combined EPS and ISS breadboard tests. 2. Start of combined subsystems tests with prototype EPS equipment.
P-8	Development of suitable method of conducting heat from electrical equipment.	1. Perform laboratory tests of heat-conducting materials to select best thermal and electrical properties.	1. EPS Design Freeze.
P-8	Continued	2. Conduct laboratory tests of prototype EPS components and subassemblies to determine if any problems exist with the thermal control technique selected. 3. Conduct thermal-vacuum tests of PCS breadboard to demonstrate thermal control capability for each PCS component/subassembly.	2. Start of PCS breadboard tests. 3. Fabrication of flight-type PCS components/subassemblies.
P-9	Ability of energy storage device to meet peak demands.	1. Conduct tests of PCS and PDS breadboards, with simulated electrical loads, to evaluate ability of the energy storage device to handle power demands during earth shadow transit.	1. Start of combined EPS and ISS breadboard tests.
P-10	Compatibility of solid-state circuit breakers with the ISS dedicated processor.	1. Conduct tests of PDS breadboard, with prototype circuit breakers controlled by dedicated processors and DPA/C&D breadboard, to evaluate the compatibility of the circuit breakers.	1. Start of combined subsystems tests with prototype EPS equipment.
P-11	Structural integrity of EPS subassemblies/assemblies during boost environment.	1. Conduct laboratory tests of prototype EPS subassemblies/assemblies to evaluate strength and rigidity for boost loads. 2. Perform dynamic tests of complete subassemblies/assemblies (flight-type) to demonstrate structural integrity of EPS equipment.	1. Start of EPS subassembly/assembly dynamic tests. 2. Installation of EPS equipment into first flight module.
P-12	Overheating of wire bundles.	1. Conduct thermal-vacuum tests of PDS to determine thermal control capability of the various wire bundles.	1. Start of combined subsystems tests with prototype EPS equipment.
P-13	Adequacy of protective circuitry to prevent propagation of component failure.	1. Conduct tests of PCS and PDS breadboards, with DPA/C&D breadboard, to evaluate the ability to sense and control simulated component failures within time limits imposed.	1. Start of combined subsystems tests with prototype EPS equipment.
P-14	Compatibility of EPS with all space station loads.	1. Evaluate compatibility of EPS (high quality power without harmonics) during tests of PCS breadboard with ISS dedicated processor and varying simulated electrical loads.	1. Start of combined subsystems tests with prototype EPS equipment.
P-15	Verification of fault-detection circuits.	1. Conduct tests of PCS and PDS breadboards, together with DPA/C&D breadboard, to determine ability to verify fault detection circuitry during normal operation of the subsystems.	1. Start of combined subsystems tests with prototype EPS equipment.

Table 2-18. Engineering Test Laboratory Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
P-16	Excessive noise produced by magnetic hardware.	1. Conduct bench tests of prototype EPS equipment to evaluate noise levels produced and evaluate various methods of attenuation.	1. Fabrication of flight-type EPS equipment.
P-17	Ability to synchronize AC units	1. Conduct laboratory tests of proto-AC units to evaluate the ability to synchronize the units when operating in parallel.	1. Start of combined subsystems tests with prototype EPS equipment.
P-18	Develop a regenerative fuel cell.	1. Conduct laboratory tests with prototype regenerative fuel cells to evaluate all operating characteristics of the units during start-up, steady-state, shut-down, and varying load conditions.	1. Start of combined EPS breadboard tests.
		2. Determine all operating characteristics of prototype regenerative fuel cells when controlled by the DPA/C&D breadboard and the PCS and PDS breadboards. Simulate various load conditions.	2. Fabrication of flight-type regenerative fuel cells.
P-19	Ability of fuel cells and energy storage combination to meet emergency loads.	1. Conduct tests with EPS breadboard, prototype secondary energy source and simulated electrical loads, to evaluate ability to meet emergency loads under worst-case operating conditions.	1. Start of combined subsystems tests with prototype EPS equipment.
A-1	Development of solar array (SA) checkout procedures.	1. Conduct tests on a prototype solar array to establish preliminary checkout procedures. 2. Conduct tests with DPA/C&D breadboard and SA simulator to determine the capability to status and check out the SA.	1. Start of combined tests of SA simulator and DPA/C&D breadboard. 2. Start of combined subsystems tests in a representative module.
A-3	Ability of all SA components and subassemblies to operate properly after exposure to the dynamic boost environment.	1. Subject all SA components and subassemblies to the boost dynamic environments to determine the adequacy of the design approach. 2. Subject flight-type SA assembly and orientation mechanism to combined environment tests to demonstrate adequacy of design.	1. Fabrication of flight-type SA assembly and orientation mechanism. 2. Installation of SA assembly and orientation mechanism into first flight power module.
A-4	Ability of solar arrays to successfully withstand repeated deployment and retraction.	1. Conduct tests on various strip assembly interconnector compositions and configurations. Select the most promising combination. 2. Conduct tests with prototype solar array strip assemblies and interconnectors to demonstrate long-life characteristics in terms of repeated deployment and retraction. 3. Conduct tests with complete deploy/retract mechanism to verify the ability to deploy/retract the SA many times in excess of the requirement.	1. SA 100% Drawing Release. 2. Start of prototype SA engineering demonstration tests. 3. Installation of SA assembly into first flight power module.

Table 2-18. Engineering Test Laboratory Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
A-5	Ability of power transfer device to withstand continuous SA orientation motions.	1. Conduct laboratory tests of sample materials to select the most promising compositions for all anticipated operating conditions. 2. Conduct motion cycling tests with prototype power transfer device to demonstrate long-life operating characteristics. Power transfer device to be subjected to high vacuum and temperature extremes while carrying nominal and maximum electrical loads. Record all parameters for trend analysis data.	1. SA 100% Drawing Release. 2. Fabrication of flight-type SA assembly.
A-6	Ability to position solar array within prescribed sun line tolerance and response time.	1. Conduct tests with orientation mechanism and sun sensing components to determine the ability to meet subsystem response criteria. 2. Conduct tests of orientation mechanism and sun sensing assemblies (with a SA mass simulator) to demonstrate the ability to meet subsystem response requirements.	1. Start of orientation mechanism closed-loop response tests. 2. Fabrication of flight-type SA assembly and orientation mechanism.
A-7	RCS plume effects on solar cell performance.	1. Conduct altitude chamber tests of SA panel segments and prototype RCS engines to determine plume effects on solar cell performance.	1. Installation of subsystems into first flight module.
A-9	Ability to reposition solar array during earth shadow transit.	1. Conduct tests with prototype orientation mechanism and SA mass simulator to determine ability to meet slew rates. 2. Conduct tests with flight-type orientation mechanism and SA mass simulator to demonstrate ability to reposition solar array.	1. Fabrication of flight-type orientation mechanism. 2. Installation of orientation mechanism into first flight module.
A-10	Ability of orientation mechanism to operate properly after prolonged exposure to earth orbital environments.	1. Subject prototype components and subassemblies to thermal-vacuum tests to determine the effects of environmental extremes and long-term exposure. 2. Subject prototype orientation mechanism to thermal-vacuum tests to demonstrate ability to operate properly after long-term exposure to simulated earth orbital environment.	1. Start of orientation mechanism environmental tests. 2. Fabrication of flight-type orientation mechanism.
A-11	Dynamic coupling of SA with MSS control system.	1. Conduct dynamic tests with prototype SA (preferably in a vacuum) to assess the validity of the dynamic response analysis procedure.	1. Fabrication of flight-type SA assembly.
A-12	Effects of folding up a hot solar array.	1. Conduct laboratory tests with prototype SA panel segments which will determine the amount of degradation when hot (180 degree) panels are folded together. 2. Conduct thermal-vacuum tests of prototype SA assembly which will demonstrate that solar cell performance is not adversely affected by folding after the heat soak period.	1. Start of prototype SA thermal-vacuum tests. 2. Fabrication of flight-type SA assembly.

Table 2-18. Engineering Test Laboratory Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
A-13	Effect of thermal cycling on solar array performance.	1. Conduct thermal cycling tests of solar cells and bus bars to determine the effects of repeated thermal transients. 2. Conduct thermal cycling tests with prototype SA panel segments to demonstrate the ability to withstand repeated thermal transients without appreciable degradation of performance.	1. SA 100% Drawing Release. 2. Fabrication of flight-type SA assembly.
A-15	Development of "on-array" switching circuits.	1. Conduct tests with prototype SA panel segments to evaluate switching circuit logic and performance. 2. Conduct tests with prototype SA assembly and orientation mechanism to demonstrate interface characteristics and the complete solar array switching logic under various electrical loads.	1. Start of prototype SA engineering demonstration tests. 2. Fabrication of flight-type SA assembly and orientation mechanism.
I-1	Development of data processing assembly (DPA) self-check capability.	1. Conduct laboratory tests with DPA/C&D breadboard and simulated subsystem interfaces to determine the suitability of the self-check procedures.	1. Start of combined subsystems tests in a representative module.
I-3	Functional compatibility of ISS with interfacing subsystems, GSE, and facility interfaces.	1. Conduct laboratory tests of prototype ISS components, with simulated interfaces, to determine the degree of compatibility of each interface. 2. Conduct tests of DPA/C&D breadboard, with simulated interfaces and varying electrical loads, to demonstrate functional compatibility of ISS.	1. Start of DPA/C&D breadboard tests. 2. Fabrication of flight-type ISS assemblies.
I-4	Electromagnetic compatibility of ISS with other subsystems, shuttle, GSE, and facility interfaces.	1. Conduct tests with prototype ISS components to determine degree of compliance with EMC requirements. 2. Conduct tests of DPA/C&D breadboard, with simulated interfaces, to demonstrate electromagnetic compatibility of ISS with other subsystems.	1. Start of DPA/C&D breadboard tests. 2. Start of combined sybsystems tests in representative module.
I-5	Communications mode switching.	1. Conduct laboratory tests of breadboard communications terminal to determine ability to switch communication modes. 2. Conduct tests with communication terminal breadboard and DPA/C&D breadboard to demonstrate ability to switch communication modes.	1. Start of communications terminal breadboard and DPA/C&D breadboard combined tests. 2. Start of combined subsystems tests in representative module.
I-6	Determination of antenna radiation patterns.	1. Conduct tests with a scaled-down directive antenna and semi-directional antennas, to determine radiation patterns of full-size antennas.	1. Fabrication of prototype, full-scale antenna.

Table 2-18. Engineering Test Laboratory Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
		2. Conduct tests with full-scale semi-directional and K-band directive antennas to demonstrate pattern predictions and to check results of VSWR estimate.	2. Installation of ISS equipment into first flight module.
I-8	Integration of all OBCO routines.	1. Conduct tests of DPA/C&D breadboard, with simulated interfaces of individual subsystems, to determine suitability of subroutine format and data rate.	1. Start of combined subsystems tests in representative module.
I-9	Ability of ISS to control EPS in all operational modes.	1. Conduct laboratory tests of DPA/C&D breadboard, with simulated interfaces, which will determine degree of functional compatibility with EPS. 2. Conduct tests with DPA/C&D breadboard and EPS breadboard combined, with varying electrical loads, to demonstrate the ability to control the EPS in all operational modes.	1. Start of DPA/C&D breadboard and EPS breadboard combined tests. 2. Start of combined subsystems tests in representative module.
I-10	Ability of ISS equipment to operate properly after exposure to the dynamic boost environment.	1. Conduct tests on prototype ISS assemblies by subjecting them to the simulated boost environment to evaluate ability to survive the boost phase.	1. Fabrication of flight-type ISS assemblies.
I-11	Ability of ISS to accept ground commands.	1. Conduct tests of prototype UDL equipment to determine compatibility with ground signal format.	1. Fabrication of flight-type UDL equipment.
I-12	Determination of most suitable method for compensating for misalignment of directive antenna.	1. Conduct laboratory tests of prototype compensation mechanism to evaluate its accuracy and repeatability.	1. Fabrication of flight-type compensation mechanism.
I-13	Ability of directive antenna to operate properly after prolonged exposure to earth-orbital environments.	1. Conduct tests with prototype antenna to determine the ability to operate properly at simulated earth-orbital environments. 2. Conduct tests with flight-type directive antenna package, in a thermal-vacuum chamber, to verify the ability to operate after prolonged exposure to earth-orbital environments.	1. Fabrication of flight-type directive antenna. 2. Assembly and acceptance of first flight antenna package.
I-14	Compatibility of both real-time and recorded data playback with telemetry ground stations for high data rate and video fidelity.	1. Conduct tests with prototype T/M equipment and digital recorder, on an RF range, to determine compatibility with telemetry ground stations.	1. Start of Skylab testing with T/M equipment and digital recorder.
I-15	Performance of RF communications within circuit performance margins and expected ranges.	1. Conduct laboratory tests which will measure losses in coax cables and connectors.	1. Fabrication of flight-type RF communications assemblies.
I-16	Ability of OBCO to effectively sample and compare IFRU data to trend data.	1. Conduct tests of DPA/C&D breadboard, with simulated source data input, to demonstrate compatibility of OBCO with all interfacing assemblies.	1. Start of combined subsystems tests in representative module.
I-17	Optimization of all displays and controls.	1. Conduct tests of DPA/C&D breadboard, with simulated subsystem interfaces, to demonstrate adequacy of all displays and controls.	1. Start of combined subsystems tests in representative module.
I-18	Development of efficient techniques for implementing real-time executive control of computer complex.	1. Conduct tests of DPA/C&D breadboard, with simulated subsystem interfaces, to determine suitability of the master executive program to handle any task/command.	1. Start of combined subsystems tests in representative module.

Table 2-18. Engineering Test Laboratory Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
I-19	Development of effective scheduling of DPA.	1. Conduct laboratory tests of DPA/C&D breadboard, with a General Purpose Subsystem computer program, to determine ability to accept and process the highest data rate.	1. Start of combined subsystems tests in representative module.
I-20	Development of computer routines for effective mission planning and mission management.	1. Conduct tests of DPA/C&D breadboard, with simulated input data, to determine effectiveness of mission planning and mission management subroutines. Prototype control console is required.	1. Start of combined subsystems tests in representative module.
I-21	Mechanization of semi-omni antenna directional switching.	1. Subject breadboard switching mechanism to laboratory tests which will determine the effectiveness of the switching logic. 2. Conduct tests of DPA/C&D breadboard, with prototype switching mechanism, to demonstrate effectiveness of the switching logic.	1. Start of DPA/C&D breadboard and prototype switching mechanism combined tests. 2. Fabrication of flight-type antenna switching mechanism.
I-22	Development of long-life RF power amplifiers and RF wide-band receiving electronics.	1. Conduct thermal-vacuum tests of prototype RF power amplifiers and RF wide-band receiving electronics to determine adequacy of design after being exposed to temperature cycling to temperature extremes for long-term period. 2. Conduct radiation tests with prototype RF power amplifiers and RF wide-band receiving electronics to determine sensitivity of the solid-state circuitry to the expected levels of radiation. 3. Subject flight-type RF power amplifiers and RF wide-band receiving electronics to all free space environments to certify these units for earth orbital operations.	1. Fabrication of flight-type RF units. 2. Fabrication of flight-type RF units. 3. Installation of RF units into first flight package.
I-23	Development of processor traffic flow control technique.	1. Conduct tests with breadboard processor circuitry to determine ability to handle pulse train data at the rate of $2.8x10^6$ BPS. Simulated pulse train data. 2. Conduct tests with DPA/C&D breadboard and breadboard control console, with simulated pulse train data at the rate of $2.8x10^6$ BPS, to determine ability to handle data at the required rate.	1. Start of DPA/C&D breadboard and processor breadboard combined tests. 2. Start of combined subsystems tests in representative module.
I-24	Development of interactive (English language) vocabulary for software modifications and crew control of the computer.	1. Conduct tests with the DPA/C&D breadboard and simulated subsystem interfaces, to determine compatibility of the software with the interfacing assemblies and with the crew.	1. Start of combined subsystems tests in representative module.
I-25	Development of high-density digital storage device.	1. Conduct tests with a prototype high density digital storage device, with simulated data inputs, to determine suitability of the design approach. 2. Conduct tests of DPA/C&D breadboard and prototype digital storage device to demonstrate capability of the digital storage device to store and retrieve data in real time.	1. Start of DPA/C&D breadboard and prototype digital storage device combined tests. 2. Start of combined subsystems tests in representative module.

Table 2-18. Engineering Test Laboratory Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
I-26	Elimination of noise effect on the data bus.	1. Subject data bus breadboard to laboratory tests which will determine its sensitivity to externally generated noise.	1. Start of combined subsystems tests in representative module.
I-27	Ability of the ISS to control all functions of the ECLSS.	1. Conduct tests, with DPA/C&D breadboard and simulated subsystem interfaces, to determine compatibility of ISS with the ECLSS interface.	1. Start of combined subsystems tests in representative module.
I-28	Develop the functional and design interface between the DPA and UTE.	1. Conduct tests with DPA/C&D breadboard and UTE simulator (computer inputs representing the UTE) to determine the feasibility of the interface design.	1. Fabrication of prototype DPA/C&D.
I-30	Ability to transfer command/ control functions between modules.	1. Conduct tests with switchover circuit breadboard to determine suitability of design to handle loads, time constraint, and no loss of data. 2. Conduct tests, with DPA/C&D breadboard and simulated subsystem interfaces, to demonstrate ability to control the transfer of command/ control functions from one module to another.	1. Fabrication of prototype ISS equipment. 2. Start of combined subsystems tests in representative module.
I-31	Ability of ISS to control all functions of the G&C.	1. Conduct tests with DPA/C&D breadboard to determine functional compatibility of the ISS with the G&C interface.	1. Start of combined subsystems tests in representative module.

Table 2-19. Static Tests Subprogram

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
S-3	Ability of module structure to sustain all loads imposed by attached equipment as a result of ground handling, checkout, boost, landing, emergency, etc.	1. Subject each representative module to (x) times design load to demonstrate structural integrity at the design condition.	1. Installation of subsystems into first flight module.
S-4	Ability of modules to withstand the effects of combined boost environment.	1. Subject unique flight-type modules to elevated temperatures and varying loads. Determine load-carrying ability at various temperatures and load distributions.	1. Installation of subsystems into first flight module.
S-16	Ability of the core module internal bulkheads to sustain maximum delta-P in either direction.	1. Subject representative core module internal bulkheads to pneumatic tests to (x) times design load to demonstrate the ability of internal bulkheads to sustain maximum delta-P.	1. Installation of subsystems into first flight module.

Table 2-20. Dynamic Environment Test Subprogram

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
E-8	Ability of ECLSS to operate within specified limits after exposure to the dynamic boost environment.	Conduct tests which will demonstrate the actual dynamic energy levels at the ECLSS equipment and measure the (partial) ECLSS equipment response to the dynamic boost environment.	Installation of subsystems into first flight module.
S-2	Effects of acoustics on structural integrity.	1. Subject each unique representative module to the predicted acoustic profile to verify structural integrity during the boost phase.	1. Installation of subsystems into first flight module.
S-6	Transmissibility of acoustic energy to subsystem equipment.	1. Subject each unique representative module to the predicted acoustic profile to verify the transmissibility factors to equipment mounted internally. Establish subsystems qualification/acceptance acoustic test criteria.	1. Start of qualification/ acceptance testing of all subsystem equipment.
S-7	Sensitivity to high-g oscillatory vibrations along the X-axis.	1. Subject a representative module to a high and low frequency vibration test program to demonstrate frequency response characteristics and modal shapes, especially in the longitudinal axis.	1. Installation of subsystems into first flight module.
G-11	Ability of the G&C to operate within specified limits after exposure to the dynamic boost environment.	1. Conduct dynamic tests with a representative module having simulated masses with c.g. locations of all G&C equipment over 50 pounds to demonstrate the actual dynamic energy levels at the G&C equipment. Measure the G&C equipment response to the simulated dynamic boost environment.	1. Installation of G&C equipment into first flight module.
G-12	Determination of outer-loop dynamics.	1. Conduct dynamic tests with representative modules, arranged in berthed configurations to verify the computer dynamic analysis program and transfer functions.	1. Installation of G&C equipment into first flight module.
P-11	Structural integrity of EPS components and equipment during boost environment.	1. Conduct tests with a representative module, having actual mass and c.g. locations of all equipment over 50 pounds, to demonstrate the actual dynamic energy levels at the EPS equipment and to measure the (partial) EPS equipment response to the dynamic boost environment.	1. Installation of subsystems into first flight module.
I-10	Ability of ISS equipment to operate properly after exposure to the dynamic boost environment.	1. Conduct dynamic tests with a representative module having simulated masses with c.g. locations of all ISS equipment over 50 pounds to demonstrate the actual dynamic energy levels at the ISS equipment. Measure the ISS equipment response to the simulated dynamic boost environment.	1. Installation of ISS equipment into first flight module.

Table 2-21. Thermal-Vacuum Tests Subprogram

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
E-23	Ability of pumpdown components to operate in time period allotted.	1. Demonstrate that pumpdown components will operate in time period allotted, by tests conducted with flight-type pumpdown components installed in representative modules. The modules would be berthed during the entire test.	1. Installation of subsystems into first flight module.
S-9	Air-tightness of pressure shell.	1. Subject the representative module to temperature cycling (maximum/minimum) while in a vacuum environment (10^{-6} torr). Measure module leakage rate.	1. Installation of subsystems into first flight module (excluding power module).
S-10	Ability to clean/replace windows without EVA.	1. Demonstrate adequacy of window mechanisms and procedures by actually cleaning/replacing windows without EVA while in a vacuum environment.	1. Installation of subsystems into first flight module (excluding power module).
S-12	Selection of optimum method of repairing micrometeoroid damage.	1. Demonstrate the ability to repair a "standard" micrometeoroid damaged section of structure.	1. Installation of subsystems into first flight module (excluding power module).
S-14	Ability to operate the airlock and flexports successfully in terms of access, pressurization, and depressurization.	1. Demonstrate ability to pressurize and depressurize the airlock; extend, mate, and retract flexports while in a vacuum environment (10^{-6} torr). Evaluate ability to replace seals. Evaluate life span of seals under these operating conditions.	1. Installation of subsystems into first flight module (excluding power module).
S-15	Minimize thermal energy gain/loss through module structure.	1. Subject a representative station module/core module to temperature soak conditions (maximum/minimum) while in a vacuum environment (10^{-6} torr). Measure heat flux, interior and exterior surface temperatures. Verify that the thermal math model can predict the total heat balance at these environmental conditions.	1. Installation of subsystems into first flight module (excluding power module).
S-19	Ability to deploy flexports between modules.	1. Conduct tests in a vacuum environment (10^{-6} torr) which will demonstrate the ability to deploy, mate & retract flexport in relation to an adjoining module which is nonparallel within limits.	1. Installation of subsystems into first flight module (excluding power module).
B-6	Opening and closing of berthing, flexport, and airlock hatches after combined environments of low temperature, high humidity, and 3.1 psia PPO_2.	1. Subject a representative module to thermal-vacuum conditions which would induce icing of the hatches (10^{-6} torr and -150°F, upper humidity limit inside module). Temperature soak for 48 hours. Measure temperature of airlock, berthing and flexport hatches, and identify any areas which might have ice buildup.	1. Installation of subsystems into first flight module.

Table 2-22. Integration Subprogram

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
R-1	Functional compatibility of RCS with other subsystems, GSE, and facility interfaces.	1. Conduct tests with prototype RCS installed in a representative module to demonstrate functional compatibility of RCS. 2. Verify functional compatibility of RCS during tests conducted with flight-type RCS installed in a representative module.	1. Start of combined subsystems tests with flight-type RCS equipment. 2. Installation of subsystems into first flight module.
R-2	Electromagnetic compatibility of RCS with interfacing subsystems.	1. Conduct tests with prototype RCS installed in a representative module to demonstrate electromagnetic compatibility of RCS. 2. Verify electromagnetic compatibility of RCS during tests conducted with flight-type RCS installed in a representative module.	1. Start of combines subsystems tests with flight-type RCS equipment 2. Installation of subsystems into first flight module.
R-3	Development of RCS checkout procedures.	1. Conduct tests with prototype RCS installed in a representative module to determine the suitability of the checkout procedures. 2. Demonstrate ability to satisfactorily check out RCS during tests conducted with flight-type RCS installed in a representative module.	1. Start of combined subsystems tests with flight-type RCS equipment. 2. Installation of subsystems into first flight module.
H-2	Determination of the optimum habitability criteria.	1. Conduct 3 or 4 week manned test in a representative module (or modules), with prototype habitability features, which will determine the suitability of the actual work/rest arrangements for the comfort and well-being of the crew. 2. Demonstrate the suitability of the MSS work/rest arrangements for the comfort and well-being of the crew by conducting tests in a representative module with flight-type habitability features installed.	1. Start of combined subsystems tests with flight-type habitability features. 2. Installation of subsystems into first flight module.
H-3	Determination of crew tasks and selection of crew equipment.	1. Conduct 3 or 4 week manned test in a representative module (or modules), with prototype life support functions, to evaluate preliminary crew tasks and crew equipment. 2. Determine suitability of crew tasks and crew equipment during tests conducted in a representative module (or modules) with flight-type life support functions.	1. Start of combined subsystems tests with flight-type life support functions. 2. Installation of subsystems into first flight module.
H-4	Establishment of crew operating procedures.	1. Conduct tests in a representative module (or modules) with prototype subsystems installed, duplicating (in part) the operational tasks planned for orbital operations, to evaluate crew proficiency in subsystems operations and in diagnosing malfunctions.	1. Start of combined subsystems tests with flight-type subsystems.

Table 2-22. Integration Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
		2. Determine the suitability of proposed operating procedures by conducting tests in a representative module (or modules) with flight-type subsystems installed, duplicating the operational tasks planned for orbital operations.	2. Checkout of first flight module.
H-5	Ability of crew to perform all man-machine tasks.	1. Conduct tests, with prototype equipment installed in a representative module, having primary or backup control, to determine ability of crew to perform all man-machine tasks. 2. Determine, by tests with flight-type equipment installed in representative module having primary or backup control, that crew can perform all man-machine tasks (possible in 1-g field).	1. Start of combined subsystems tests with flight-type equipment. 2. Installation of subsystems into first flight module.
H-6	Interface compatibility of government furnished equipment (GFE) with the Modular Space Station.	1. Conduct manned tests with prototype GFE installed in representative modules, to determine compatibility of GFE and Modular Space Station. 2. Demonstrate, by manned tests with flight-type GFE installed in representative modules, that all GFE is compatible with the Modular Space Station.	1. Start of combined subsystems tests with flight-type GFE. 2. Installation of subsystems into first flight module.
H-8	Adequacy of internal lighting.	1. Conduct tests, with prototype lighting installed in representative modules, to determine that correct level of lighting is provided for specific task areas. 2. Demonstrate, by tests with flight-type lighting installed in representative modules, that correct lighting levels have been provided throughout the Modular Space Station.	1. Start of combined subsystems tests with flight-type lighting. 2. Installation of subsystems into first flight module.
E-1	Development of ECLSS checkout procedures.	1. Conduct tests with SSP installed in a representative module, which will determine the suitability of the checkout procedures. 2. Demonstrate suitability of the checkout procedures by tests, conducted with flight-type ECLSS installed in representative modules, which are connected to the Integration Test Tool.	1. Start of combined subsystems test with flight-type ECLSS equipment. 2. Installation of subsystems into first flight module.
E-2	Accessibility of ECLSS equipment for installation, inspection,	1. Demonstrate accessibility of ECLSS equipment during installation of flight-type equipment into the representative modules.	1. Installation of subsystems into first flight module.
E-3	Functional compatibility of ECLSS with interfacing subsystems, GSE, and facility interfaces.	1. Conduct tests, which will demonstrate functional compatibility, with SSP installed in a representative module. Simulate functional interfaces.	1. Start of combined subsystems test with flight-type ECLSS equipment.

Table 2-22. Integration Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
		2. Demonstrate functional compatibility by tests conducted with flight-type ECLSS, installed in representative modules, which are connected to the Integration Test Tool.	2. Installation of subsystems into first flight module.
E-4	Electromagnetic compatibility of ECLSS with other subsystems, GSE, and facility interfaces.	1. Conduct tests with SSP installed in a representative module, which will determine the intersystem electromagnetic compatibility (partial) between ECLSS and all interfacing subsystems.	1. Start of combined subsystems test with flight-type ECLSS equipment.
		2. Demonstrate intersystem electromagnetic compatibility by tests conducted with flight-type ECLSS installed in representative modules which are connected to the Integration Test Tool.	2. Installation of subsystems into first flight module.
		3. Verify electromagnetic compatibility during tests with flight ECLSS installed in flight module.	3. Launch of first flight module.
E-5	Development of coldplate approach.	1. Conduct tests with SSP installed in a representative module which will determine the suitability (partial) of the coldplate design.	1. Start of combined subsystems tests with flight-type ECLSS equipment.
		2. Demonstrate suitability of the coldplate design during tests of flight-type coldplates installed in representative modules.	2. Installation of subsystems into first flight module.
E-6	Protection of thermal-control coating after installation.	1. Determine suitability of protective shield after installation of the shield on a representative module.	1. Installation of ECLSS radiator protective shield on first flight module.
E-9	Ability of ECLSS to maintain water vapor (relative humidity) within tolerance.	1. Conduct tests with SSP humidity control heat exchanger, installed in a representative module, to determine the ability to control relative humidity.	1. Start of combined subsystems tests with flight-type ECLSS equipment.
		2. Demonstrate ability to control relative humidity in all modules during tests of flight-type ECLSS installed in representative modules.	2. Installation of subsystems into first flight module.
E-10	Ability of ECLSS to adequately remove CO_2, odors, debris, and contaminants.	1. Conduct tests with prototype hydrogen depolarizer and catalytic oxidizer units, installed in a representative module which will determine the ability to control contaminants and toxicity.	1. Start of combined subsystems tests with flight-type ECLSS equipment.
		2. Demonstrate ability to control relative humidity in all modules during tests of flight-type ECLSS installed in representative modules.	2. Installation of subsystems into first flight module.
E-11	Ability of ECLSS to maintain proper O_2/N_2 partial pressure relationship.	1. Conduct tests with prototype regulator assemblies installed in a representative module which will determine the ability to maintain proper partial pressures.	1. Start of combined subsystems tests with flight-type ECLSS equipment.
		2. Demonstrate the ability to maintain partial pressure relationships during tests of flight-type partial pressure regulator assemblies installed in representative modules.	

Table 2-22. Integration Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
E-12	Ability of ECLSS to maintain correct temperature at coldplate inlets.	1. Conduct tests, with prototype heat exchangers in the active thermal control loop, to demonstrate that the temperature range to the inlet of all coldplates can be maintained. 2. Verify the ability to maintain the temperature range to the inlet of all coldplates during tests with flight-type heat exchangers and active thermal control subsystem installed in representative module.	1. Start of combined subsystems test with flight-type heat exchangers and active thermal control loop. 2. Installation of subsystems into first flight module.
E-13	Ability of sterilization equipment to adequately control purity of water.	1. Conduct tests with prototype sterilization control components installed in representative module to demonstrate the ability to control water purity. 2. Verify the ability to control water purity by tests of the flight-type sterilization control components installed in a representative module.	1. Start of combined subsystems test with flight-type sterilization control components. 2. Installation of subsystems into first flight module.
E-14	Ability of urine, condensate, wash water, and waste water recovery circuit to adequately reclaim water.	1. Conduct tests,with prototype vapor compression stills and associated components (pumps, conductivity sensors, etc.) installed in representative modules, to demonstrate the ability to reclaim water. Actual operation of urinals and wash cycles is required. 2. Verify the ability to reclaim water by tests of the flight-type vapor compression stills and associated components installed in a representative module.	1. Start of combined subsystems test with flight-type compression stills and associated components. 2. Installation of subsystems into first flight module.
E-15	Ability of water electrolysis unit to produce O_2/H_2 at the required rate.	1. Conduct tests, with prototype electrolysis stacks installed in a representative module, to determine the ability to produce O_2/H_2 at the required rate. 2. Demonstrate the ability to produce O_2/H_2 at the required rate during tests with flight-type electrolysis stacks installed in a representative module.	1. Start of combined subsystems test with flight-type electrosis stacks. 2. Installation of subsystems into first flight module.
E-16	Ability of all condensers to extract water efficiently.	1. Conduct tests, with prototype condensing heat exchangers installed in a representative module, to determine the ability to extract all water collected in the various condensers. 2. Demonstrate the ability to extract all water collected during tests of flight-type condensing heat exchangers installed in a representative module.	1. Start of combined subsystems test with flight-type condensing heat exchangers. 2. Installation of subsystems into first flight module.

Table 2-22. Integration Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
E-17	Ability to limit equipment noise to acceptable level.	1. Conduct tests, with prototype pumps, fans, and blowers installed in a representative module, to determine the ability to limit equipment noise to acceptable levels. 2. Demonstrate the ability to limit equipment noise by tests of flight-type pumps, fans, and blowers installed in a representative module.	1. Start of combined subsystems test with flight-type pumps, fans, and blowers. 2. Installation of subsystems into first flight module.
E-18	Balance subsystem for proper airflow in each module.	1. Conduct tests, with prototype air ducts, diffusers, registers, and circulation fans installed in a representative module, to determine that the atmospheric control can be balanced and fans strategically located for efficient air circulation. 2. Demonstrate that the atmospheric control can be balanced and fans strategically located during tests of flight-type ducts, diffusers, registers, and circulation fans installed in a representative module.	1. Start of combined subsystems tests with flight-type air ducts, diffusers, registers, and circulation fans. 2. Installation of subsystems into first flight module.
E-19	Ability to remove and replace IFRUs without spillage or trapping air in liquid lines.	1. Conduct tests, with prototype disconnects installed in a representative module to determine that no spillage occurs and no air is trapped in liquid lines when IFRUs are removed and replaced. 2. Demonstrate that the flight-type disconnects will not spill liquid or trap air during the remove and replace operations associated with testing IFRUs in a representative module.	1. Start of combined subsystems tests with flight-type disconnects. 2. Installation of subsystems into first flight module.
E-22	Corrosion effects of the water management assembly.	1. Conduct tests, with prototype ECLSS equipment installed in a representative module, to demonstrate that corrosion products will not be a major problem in the plumbing and components. Test should last 3-4 weeks with crew actually living aboard and using the ECLSS subsystem. 2. Demonstrate that corrosion products will not be a major problem during tests of flight-type ECLSS assemblies installed in a representative module. Test should last 3-4 weeks (or longer) with crew actually living aboard and using the ECLSS subsystem.	1. Start of combined subsystems tests with flight-type ECLSS equipment. 2. Installation of subsystems into first flight module.
S-9	Air-tightness of pressure shell.	1. Conduct leakage test on each ground test module to verify that manufacturing processes and procedures can keep leakage rate within specification value.	1. Acceptance of first flight module.

Table 2-22. Integration Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
B-1	Functional compatibility of electrical and fluid interfaces across the berthing interface.	1. Conduct tests with a representative module berthed to the Integration Test Tool, with simulated subsystem interfaces, to verify the functional compatibility of the berthing interface.	1. Installation of subsystems into first flight module.
G-1	Mechanization of G&C control modes.	1. Conduct tests with prototype G&C and control console, installed in a representative module, to demonstrate ability to perform the various G&C modes in an efficient manner. 2. Verify efficiency of all G&C modes during tests with flight-type G&C equipment installed in a representative module.	1. Start of combined subsystems tests with flight-type G&C equipment. 2. Installation of subsystems into first flight module.
G-2	Development of optical reference and inertial reference pre-processor software.	1. Conduct tests with prototype pre-processor installed in a representative module with all interfacing prototype subsystems and associated software available, to demonstrate the compatibility of the software with all pre-processor functions. 2. Verify the compatibility of the the software with optical and inertial reference pre-processors by tests conducted with flight-type G&C and ISS equipment installed in a representative module.	1. Start of combined subsystems tests with flight-type G&C equipment. 2. Checkout of first flight module.
G-3	Development of inflight maintenance concepts.	1. Conduct tests with prototype G&C prototype G&C equipment installed in a representative module to determine the effect of the preliminary inflight maintenance procedures. 2. Demonstrate the validity of the inflight maintenance procedures by tests conducted with flight-type G&C equipment installed in a representative module.	1. Start of combined subsystems tests with flight-type G&C equipment. 2. Checkout of first flight module.
G-6	Development of G&C checkout procedures.	1. Conduct tests with prototype G&C and DPA/C&D, installed in a representative module, to determine the adequacy of the G&C checkout procedures. 2. Demonstrate adequacy of the G&C checkout procedures during tests conducted with flight-type GSE and ISS equipment installed in a representative module.	1. Start of combined subsystems tests with flight-type G&C and ISS equipment. 2. Installation of subsystems into first flight module.
G-7	Functional compatibility of G&C with interfacing subsystems, GSE, and facility interfaces.	1. Conduct tests with prototype G&C equipment installed in a representative module to demonstrate functional compatibility. 2. Verify functional compatibility of G&C during tests conducted with flight-type G&C equipment installed in a representative module with all interfacing subsystems present.	1. Start of combined subsystems tests with flight-type G&C equipment. 2. Installation of subsystems into first flight module.

Table 2-22. Integration Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
G-8	Electromagnetic compatibility of G&C with interfacing subsystems.	1. Conduct tests with prototype G&C equipment, installed in a representative module, to demonstrate electromagnetic compatibility of G&C. 2. Verify electromagnetic compatibility of G&C during tests conducted with flight-type G&C equipment installed in a representative module with all interfacing subsystems present.	1. Start of combined subsystems tests with flight-type G&C equipment. 2. Installation of subsystems into first flight module.
G-9	Alignment of optical and inertial devices.	1. Conduct tests with prototype G&C mounting and alignment equipment, with respective optical and inertial devices, to determine the accuracy of the technique. 2. Demonstrate the accuracy of the optical and inertial alignment technique during tests conducted with flight-type G&C mounting and alignment equipment, with respective optical and inertial devices, installed in a representative module.	1. Start of combined subsystem tests with flight-type G&C equipment. 2. Installation of subsystems into first flight module.
G-16	Ability to detect G&C electromechanical failures and provide warning.	1. Conduct tests with prototype G&C and ISS equipment installed in a representative module to determine the ability to detect electromechanical failures and provide ISS display. 2. Demonstrate the ability to detect electromechanical failures and provide ISS display during tests conducted with flight-type G&C and ISS equipment installed in a representative module.	1. Start of combined subsystems tests with flight-type G&C and ISS equipment. 2. Installation of subsystems into first flight module.
G-19	Ability of stabilization system to stabilize initial modules.	1. Conduct tests with prototype interim G&C functions installed in a representative module to demonstrate the ability of the interim G&C to control the MSS within spec limits. 2. Verify the ability of the interim G&C to control the MSS within spec limits during tests conducted with flight-type interim G&C functions installed in a representative module.	1. Start of combined subsystems tests with flight-type interim G&C functions. 2. Installation of subsystems into first flight module.
P-1	Compatibility of inverters with dedicated processors.	1. Conduct combined subsystems tests with prototype PCS installed in a representative module to determine degree of compatibility of inverters with the dedicated processors. 2. Demonstrate compatibility of inverters with dedicated processors during tests with flight-type PCS installed in a representative module with interfacing subsystems.	1. Start of combined subsystems tests with flight-type EPS equipment. 2. Installation of subsystems into first flight module.
P-2	Development of power distribution system checkout procedures.	1. Conduct tests with prototype PDS, installed in a representative module with interfacing subsystems, to determine validity of preliminary checkout procedures.	1. Start of combined subsystems tests with flight-type EPS equipment.

Table 2-22. Integration Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
		2. Demonstrate validity of final checkout procedures by tests with flight-type PDS installed in a representative module with interfacing subsystems.	2. Installation of subsystems into first flight module.
P-3	Development of power conditioning system (PCS) checkout procedures.	1. Conduct tests with prototype PCS installed in a representative module with interfacing subsystems, to determine validity of preliminary checkout procedures. 2. Demonstrate validity of final checkout procedures by tests with flight-type PCS installed in a representative module with interfacing subsystems.	1. Start of combined subsystems tests with flight-type EPS equipment. 2. Installation of subsystems into first flight module.
P-4	Functional compatibility of EPS with other subsystems, GSE, and facility interfaces.	1. Conduct tests, with PCS and PDS breadboards, DPA/C&D breadboard (with control consoles), and prototype ECLSS (SSP) installed in a representative module, to determine the functional compatibility of the EPS. 2. Demonstrate functional compatibility of the EPS by tests with flight-type PCS and PDS installed in a representative module with all interfacing subsystems.	1. Start of combined subsystems tests with flight-type EPS equipment. 2. Installation of subsystems into first flight module.
P-5	Accessibility of EPS equipment and components for installation, inspection, and maintenance.	1. Determine clearances and space available for accessibility during installation of prototype PCS and PDS into a representative module. 2. Demonstrate room for accessibility during installation of flight-type PCS and PDS into a representative module.	1. Fabrication of flight-type EPS equipment. 2. Installation of subsystems into first flight module.
P-6	Electromagnetic compatibility of EPS with other subsystems, GSE,	1. Conduct tests with prototype EPS equipment installed in a representative module, to determine areas of electromagnetic incompatibility of EPS. 2. Demonstrate electromagnetic compatibility of EPS by tests with flight-type EPS equipment installed in a representative module with all interfacing subsystems.	1. Start of combined subsystems tests with flight-type EPS equipment. 2. Installation of subsystems into first flight module.
P-7	Optimization of EPS to the normal and maximum electrical load profiles.	1. Conduct tests with prototype PCS and PDS installed in a representative module, with simulated interfaces, to demonstrate capability to meet full range of electrical loads with no deleterious effects. 2. Verify ability of EPS to meet full range of electrical loads by tests of flight-type EPS installed in a representative module with simulated interfaces.	1. Start of combined subsystems tests with flight-type EPS equipment. 2. Installation of subsystems into into first flight module.

Table 2-22. Integration Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
P-8	Development of suitable method of conducting heat from electrical equipment.	1. Conduct tests with prototype PCS installed in a representative module, with ECLSS cooling loop, to demonstrate ability to dissipate heat generated. 2. Verify ability to dissipate heat generated by tests of flight-type PCS installed in a representative module with ECLSS cooling loop active.	1. Start of combined subsystems tests with flight-type EPS equipment. 2. Installation of subsystems into first flight module.
P-9	Ability of energy storage device to meet peak demands.	1. Conduct tests of prototype PCS and PDS, installed in a representative module with simulated electrical loads, to determine ability of energy storage device to meet peak demands. 2. Demonstrate ability of energy storage device to meet peak demands by tests of flight-type PCS and PDS installed in a representative module with all interfacing subsystems.	1. Start of combined subsystems tests with flight-type EPS equipment. 2. Installation of subsystems into first flight module.
P-10	Compatibility of solid-state circuit breakers with dedicated processors.	1. Conduct combined subsystems tests with prototype C/B's installed in a representative module, with dedicated processors, to determine compatibility of C/B's. 2. Demonstrate compatibility of C/B's by tests of flight-type EPS installed in a representative module with all subsystem interfaces.	1. Start of combined subsystems tests with flight-type EPS equipment. 2. Installation of subsystems into first flight module.
P-12	Overheating of wire bundles.	1. Conduct combined subsystems tests with prototype EPS installed in a representative module with simulated subsystems loads, to demonstrate adequate heat conduction from wire bundles. 2. Verify ability to adequately remove heat from wire bundles by tests of flight-type EPS installed in a representative module, with all subsystem loads.	1. Start of combined subsystems tests with flight-type EPS equipment. 2. Installation of subsystems first flight module.
P-13	Adequacy of protective circuitry to prevent propagation of component failure.	1. Conduct tests with prototype EPS equipment installed in a representative module, with interfacing subsystems and simulated loads, to determine that protective circuitry will prevent propagation of component failure. 2. Demonstrate that protective circuitry will prevent propagation of component failures during tests of flight-type EPS equipment installed in a representative module.	1. Start of combined subsystems tests with flight-type EPS equipment. 2. Installation of subsystems into first flight module.
P-14	Compatibility of EPS will all Space Station loads.	1. Conduct tests, with prototype EPS equipment installed in a representative module with interfacing subsystems and simulated loads, to determine the compatibility of the EPS with all space station loads (profiles). 2. Demonstrate the compatibility of the EPS with all space station loads during tests of flight-type EPS equipment installed in a representative module.	1. Start of combined subsystem tests with flight-type EPS equipment. 2. Installation of subsystems into first flight module.

Table 2-22. Integration Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
P-15	Verification of fault-detection circuits.	1. Conduct combined subsystem tests with representative power module (having prototype EPS equipment installed) to demonstrate the ability to status fault detection circuitry during normal subsystems operation. 2. Conduct combined subsystem tests with representative power module (having flight-type EPS equipment installed) connected to simulated subsystem interfaces, to verify the ability to status the fault detection circuitry during normal subsystems operation.	1. Start of combined subsystem tests with flight-type EPS equipment. 2. Installation of subsystems into first flight module.
P-16	Excessive noise produced by magnetic hardware.	1. Determine the acceptable level of noise produced by magnetic hardware during tests conducted with prototype EPS equipment installed in a representative module with simulated interface loads. 2. Demonstrate acceptable noise level produced by magnetic hardware during tests conducted with flight-type EPS equipment installed in a representative module with all subsystem interfaces.	1. Start of combined subsystems tests with flight-type EPS equipment. 2. Installation of subsystems into
P-17	Ability to synchronize AC units operating in parallel.	1. Conduct tests of prototype EPS installed in a representative module with prototype CTE and simulated interface loads, to determine the ability to synchronize AC units operating in parallel. 2. Demonstrate ability to synchronize AC units operating in parallel by tests conducted with flight-type EPS installed in a representative module with all subsystem interfaces.	1. Start of combined subsystems tests with flight-type EPS equipment. 2. Installation of subsystems into first flight module.
P-19	Ability of fuel cells and energy storage combination to meet emergency loads.	1. Conduct tests with prototype EPS (including fuel cells and energy storage device) installed in a representative module to determine the ability to meet emergency loads with no adverse effects. 2. Demonstrate ability of fuel cells and energy storage device to meet emergency loads by tests of flight-type EPS installed in a representative module with all subsystem interfaces.	1. Start of combined subsystems tests with flight-type EPS equipment. 2. Installation of subsystems into first flight module.
A-1	Development of solar array (SA) checkout procedures.	1. Conduct tests with the SA simulator berthed to the Integration Test Tool, with simulated interfaces, to verify ability of the OBCO to status and checkout the solar array.	1. Checkout of first flight power module.
A-2	Ability to handle, install, and align solar array.	1. Conduct tests with SA simulator and representative power module berthed to the Integration Test Tool, with simulated interfaces, to verify the ability to align SA with C&D.	1. Installation of SA assembly into first flight power module.

Table 2-22. Integration Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
A-15	Development of "on-array" switching circuits.	1. Verify the ability to control power coming from the solar array (simulator) during tests with representative power module and SA simulator, berthed to the Integration Test Tool.	1. Installation of SA assembly into first flight power module.
I-1	Development of data processing assembly (DPA) self-check capability.	1. Conduct tests with prototype DPA installed in a representative module to demonstrate self-check capability of the DPA. 2. Verify self-check capability of the DPA by tests with flight-type DPA installed in a representative module.	1. Start of combined subsystems tests with flight-type ISS equipment. 2. Installation of subsystems into first flight module.
I-2	Accessibility of ISS equipment for installation, inspection, maintenance, and repair.	1. Conduct fit checks and dimensional verifications during installation of prototype ISS equipment into a representative module. 2. Demonstrate that adequate accessibility is provided as flight-type ISS equipment is installed in representative modules.	1. Installation of flight-type ISS equipment into representative module. 2. Installation of subsystems into first flight module.
I-3	Functional compatibility of ISS with interfacing subsystems, GSE, and facility interfaces.	1. Conduct combined subsystems tests with prototype ISS equipment installed in a representative module. Demonstrate functional compatibility of ISS. 2. Demonstrate functional compatibility of ISS with all other interfacing subsystems during tests conducted with flight-type ISS equipment installed in representative module.	1. Start of combined subsystems tests with flight-type ISS equipment. 2. Installation of subsystems into first flight module.
I-4	Electromagnetic compatibility of ISS with other subsystems, shuttle, GSE, and facility interfaces.	1. Conduct combined subsystems tests with prototype ISS equipment installed in a representative module to demonstrate electromagnetic compatibility of ISS. 2. Verify electromagnetic compatibility of ISS during tests with flight-type ISS equipment installed in a representative module.	1. Start of combined subsystems with flight-type ISS equipment. 2. Installation of subsystems into first flight module.
I-5	Communications mode switching.	1. Demonstrate the ability of the ISS to switch from one mode to another (i.e., voice, video, data, internal, etc.) by tests conducted with flight-type ISS equipment installed in a representative module.	1. Installation of subsystems into first flight module.
I-7	Adequacy of internal communications.	1. Conduct tests, with prototype internal communications installed in a representative module(s), to determine the compatibility of all communication functions. 2. Demonstrate the compatibility of all internal communication functions during tests of flight-type internal communication equipment installed in representative modules.	1. Start of combined subsystems tests with flight-type internal communication equipment. 2. Installation of subsystems into first flight module.

Table 2-22. Integration Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
I-8	Integration of all OBCO routines.	1. Conduct tests, with prototype DPA/C&D equipment installed in a representative module which is berthed to the Integration Test Tool, to determine the success of the integration of all subroutines. 2. Conduct tests, with flight-type DPA/C&D equipment installed in a representative module which is berthed to the Integration Test Tool, to demonstrate the success of the integration of all OBCO subroutines.	1. Start of combined subsystem tests with flight-type ISS equipment. 2. Checkout of first flight module.
I-9	Ability of ISS to control EPS in all operational modes.	1. Conduct tests with prototype ISS and EPS equipment installed in a representative module to demonstrate ability of ISS to control EPS in all operational modes. 2. Verify the ability of ISS to control EPS circuit breakers, timing signals, load management, etc. by conducting tests with flight-type ISS and EPS equipment installed in representative modules.	1. Start of combined subsystems tests with flight-type ISS and EPS equipment. 2. Installation of subsystems into first flight module.
I-12	Determination of most suitable method for compensating for misalignment of directive antenna.	1. Conduct tests with prototype compensating mechanism installed in a representative module, with antenna package installed, to determine accuracy of mechanism to compensate for misalignment. 2. Demonstrate the ability to accurately compensate for misalignment of directive antenna by tests conducted with flight-type compensating mechanism and antenna package installed in a representative module.	1. Start of combined subsystems tests with flight-type ISS equipment. 2. Installation of subsystems into first flight module with antenna package.
I-16	Ability of OBCO to effectively sample and compare IFRU data to trend data.	1. Conduct tests with DPA/C&D breadboard, EPS breadboard, and prototype ECLSS (SSP) installed in a representative module, to determine the ability of the OBCO to gather and compare IFRU data to trend data. 2. Demonstrate the ability of the OBCO to effectively gather and compare IFRU data to trend data during tests conducted with flight-type ISS, EPS, and ECLSS equipment installed in a representative module.	1. Start of subsystems tests with flight-type ISS, EPS, and ECLSS equipment. 2. Installation of subsystems into first flight module.
I-17	Optimization of all displays and controls.	1. Conduct tests with DPA/C&D breadboard, EPS breadboard, and prototype ECLSS (SSP) installed in a representative module to demonstrate the adequacy of all displays and controls. 2. Verify the adequacy of all displays and controls during tests conducted with flight-type ISS, EPS, and ECLSS installed in a representative module.	1. Start of combined subsystem tests with flight-type ISS, EPS, and ECLSS equipment. 2. Installation of subsystems into first flight module.

Table 2-22. Integration Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
I-18	Development of efficient techniques for implementing real-time executive control of computer complex.	1. Conduct tests with DPA/C&D breadboard, EPS breadboard, and prototype ECLSS (SSP) installed in a representative module to determine suitability of the executive program. 2. Demonstrate efficiency of executive program by conducting tests with flight-type ISS, EPS, and ECLSS, installed in a representative module.	1. Start of combined subsystem tests with flight-type ISS, EPS, and ECLSS equipment. 2. Checkout of first flight module.
I-19	Development of effective scheduling of DPA.	1. Conduct tests with DPA/C&D breadboard, EPS breadboard, and prototype ECLSS (SSP) installed in a representative module to determine ability to effectively utilize all the computer capability. 2. Demonstrate ability to effectively utilize all the computer capability during tests conducted with flight-type ISS, EPS, and ECLSS equipment installed in a representative module.	1. Start of combined subsystems tests with flight-type ISS, EPS, and ECLSS equipment. 2. Checkout of first flight module.
I-20	Development of computer routines for effective mission planning and mission management.	1. Conduct tests with DPA/C&D breadboard, EPS breadboard, and prototype ECLSS (SSP) installed in a representative module to determine compatibility of all mission planning and mission management routines. 2. Demonstrate compatibility of all mission planning and mission management routines during tests conducted with flight-type ISS, EPS, and ECLSS equipment installed in a representative module. Simulate all inputs from RAM, Shuttle, DRAM, TDRS, and Ground.	1. Start of combined subsystems tests with flight-type ISS, EPS, and ECLSS equipment. 2. Checkout of first flight module.
I-21	Mechanization of semi-omni antenna directional switching.	1. Demonstrate ability to properly switch antennas, as directed, during tests conducted with flight-type switching mechanism and antenna package installed in a representative module.	1. Installation of subsystems into first flight module.
I-23	Development of central processor traffic flow control technique.	1. Demonstrate ability of the I/O units to handle pulse train data effectively during tests conducted with flight-type ISS equipment installed in representative modules having primary control center and backup control center.	1. Checkout of first flight
1-24	Development of interactive (English language) vocabulary for software mods and crew control of computer.	1. Conduct tests with DPA/C&D breadboard, EPS breadboard, and prototype ECLSS (SSP) installed in a representative module to determine the ability to make minor changes in the software. 2. Demonstrate the ability to make minor changes in the software during tests conducted with flight-type ISS, EPS, and ECLSS equipment installed in a representative module.	1. Start of combined subsystems tests with flight-type ISS, EPS, and ECLSS equipment. 2. Checkout of first flight module.

Table 2-22. Integration Subprogram (Cont)

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
I-25	Development of high-density storage device.	1. Conduct tests with DPA/C&D breadboard, EPS breadboard, and prototype ECLSS (SSP) installed in a representative module, to demonstrate suitability of high-density storage device to acquire, store and retrieve data.	1. Start of combined subsystems tests with flight-type ISS, EPS, and ECLSS equipment.
I-26	Elimination of noise effect on the data bus.	1. Conduct tests with DPA/C&D breadboard, data bus breadboard, EPS breadboard, and prototype ECLSS (SSP) installed in a representative module to determine degree of isolation of noise sources. 2. Demonstrate successful isolation of noise sources during tests of flight-type ISS, EPS, and ECLSS equipment installed in a representative module.	1. Start of combined subsystems tests with flight-type ISS equipment. 2. Installation of subsystems into first flight module.
I-27	Ability of ISS to control all functions of the ECLSS.	1. Conduct tests with DPA/C&D breadboard and prototype ECLSS (SSP) installed in a representative module to determine ISS control and statusing capability. 2. Demonstrate ability of ISS to control all functions of the ECLSS during tests with flight-type ISS and ECLSS equipment installed in a representative module.	1. Start of combined subsystem tests with flight-type ISS equipment. 2. Installation of subsystems into first flight module.
I-30	Ability to transfer command/control functions.	1. Conduct tests with prototype ISS equipment (control consoles) installed in representative modules having primary and backup control centers to demonstrate the ability to transfer control between centers. 2. Verify the ability to transfer control between centers during tests conducted with flight-type ISS equipment (control consoles) installed in representative modules having primary and backup control centers.	1. Start of combined subsystems tests with flight-type ISS equipment. 2. Installation of subsystems into first flight module having primary and backup control centers.
I-31	Ability of ISS to control all functions of the G&C.	1. Conduct tests with DPA/C&D breadboard and prototype G&C equipment installed in a representative module to determine ISS control capability. 2. Demonstrate ability of ISS to control all functions of the G&C during tests of flight-type ISS and G&C equipment installed in a representative module.	1. Start of combined subsystems tests with flight-type ISS equipment. 2. Installation of subsystems into first flight module.

Table 2-23. Flight Demonstration Subprogram

NO.	DEVELOPMENT ISSUE	TASK	EVENT SUPPORTED OR CONSTRAINED
H-7	Adequacy of crew accessories and restraint devices.	1. Demonstrate the ability of crewmen to perform certain tasks with tools, restraint devices, and simulated work areas by Skylab Program tests.	1. Installation of crew accessories and restraint devices into first flight module.
H-11	Ability of suited crewman to open and close any hatch in zero-g.	1. Demonstrate the ability of a suited crewman to open and close simulated airlock hatches during tests in Skylab Program.	1. Installation of hatches into first flight core module.
H-13	Effects of long-term zero gravity on crew health and safety.	1. Evaluate the effect of calcium rich diets and drugs which inhibit decalcification during 14 day Apollo missions. Also evaluate drugs which speed-up heartbeat (during periods if inactivity). 2. Determine the benefits to be derived from the use of crew recreation equipment during a 28 day mission of Skylab. Measure tolerance increase to accept re-entry conditions. 3. Determine the benefits to be derived from the use of crew recreation equipment during a 56 day mission of Skylab. Measure tolerance increase to accept re-entry conditions.	1. Skylab 28 day crew evaluation mission. 2. Skylab 56 day crew evaluation mission. 3. MSS 90 day crew evaluation mission.
E-20	Degradation of thermal control coating by the venting of gases and fluids.	1. Conduct tests in Skylab Program which will determine the affinity of vented fluids (similar to MSS fluids) to the radiators. Measure heat rejection before and after the test to estimate the degradation effects.	1. Fabrication of flight-type radiators.
S-12	Selection of optimum method of repairing micrometeoroid damage.	1. Demonstrate the effectiveness of the recommended materials and procedures by repairing several simulated micrometeoroid punctures in Skylab Program.	1. Launch of first flight module.
I-11	Ability of ISS to accept ground commands.	1. Conduct tests in the Skylab Program with prototype UDL to demonstrate the ability of the ISS assemblies to accept ground commands (during the pre-manning period).	1. Installation of UDL equipment into first flight module.
I-14	Compatibility of both real-time and recorded data playback with telemetry ground station for high data rate and video fidelity.	1. Conduct tests in the Skylab Program, with prototype telemetry equipment and digital recorder, to demonstrate compatibility with the telemetry ground stations.	1. Installation of telemetry equipment and digital recorders into first flight module.

3. MANUFACTURING

3.1 PURPOSE

This section describes the Space Division's approach to manufacturing operations during Phases C and D of the Modular Space Station Program. It defines requirements for planning and controlling manufacturing operations to assure that all products conform to engineering specifications and drawings and are delivered on time at minimum cost.

3.2 SCOPE

This section covers manufacturing operations for Phases C and D of the Modular Space Station Program as related to MSS element hardware. The manufacturing operations include the following:

Manufacturing engineering and development

Resources planning

Production control

Production planning

Special tooling and supporting equipment

Fabrication, assembly, and installation

In-process verification

Delivery

3.3 MANUFACTURING

The MSS manufacturing process is used to identify tasks, requirements, products, and interfaces for the production of the contract end-items. The manufacturing process is shown in Figure 3-1.

3.3.1 MANUFACTURING ENGINEERING AND DEVELOPMENT

The advanced manufacturing engineering and development activities during Phases C and D will assure that all engineering requirements are translated into an efficient and economical manufacturing plan. An advanced manufacturing engineering and development logic flow is shown in Figure 3-2.

During the design phase, and when necessary during the production phase, the Manufacturing Engineering and Development function will conduct feasibility reviews with engineering to assure maximum utilization of manufacturing resources and clarification of engineering requirements. These reviews also serve as the communications link with other functions. The functional requirements of manufacturing engineering and development are defined in the following paragraphs.

Manufacturing and Engineering Interface

Manufacturing Engineering will analyze system and design engineering data, conduct manufacturability analyses, and conduct feasibility reviews with engineering to examine concepts, issues, proposed changes, safety considerations, and cost-avoidance items. Manufacturing Engineering will assist engineering in the development of practical designs and participate in all formal design reviews.

Development

Prior to or during review of advance engineering data, requirements will be developed for manufacturing facilities, long-lead-time procurement, work-station area support, make or buy, and manufacturing testing.

Existing facilities will be considered in determining the requirements for manufacture of MSS hardware. Facility requirements, including those for conversion, are discussed in Section 5.

Long-lead-time procurement requirements will be determined by identification of items or materials necessary to support major tooling, production and test hardware, and manufacturing test equipment.

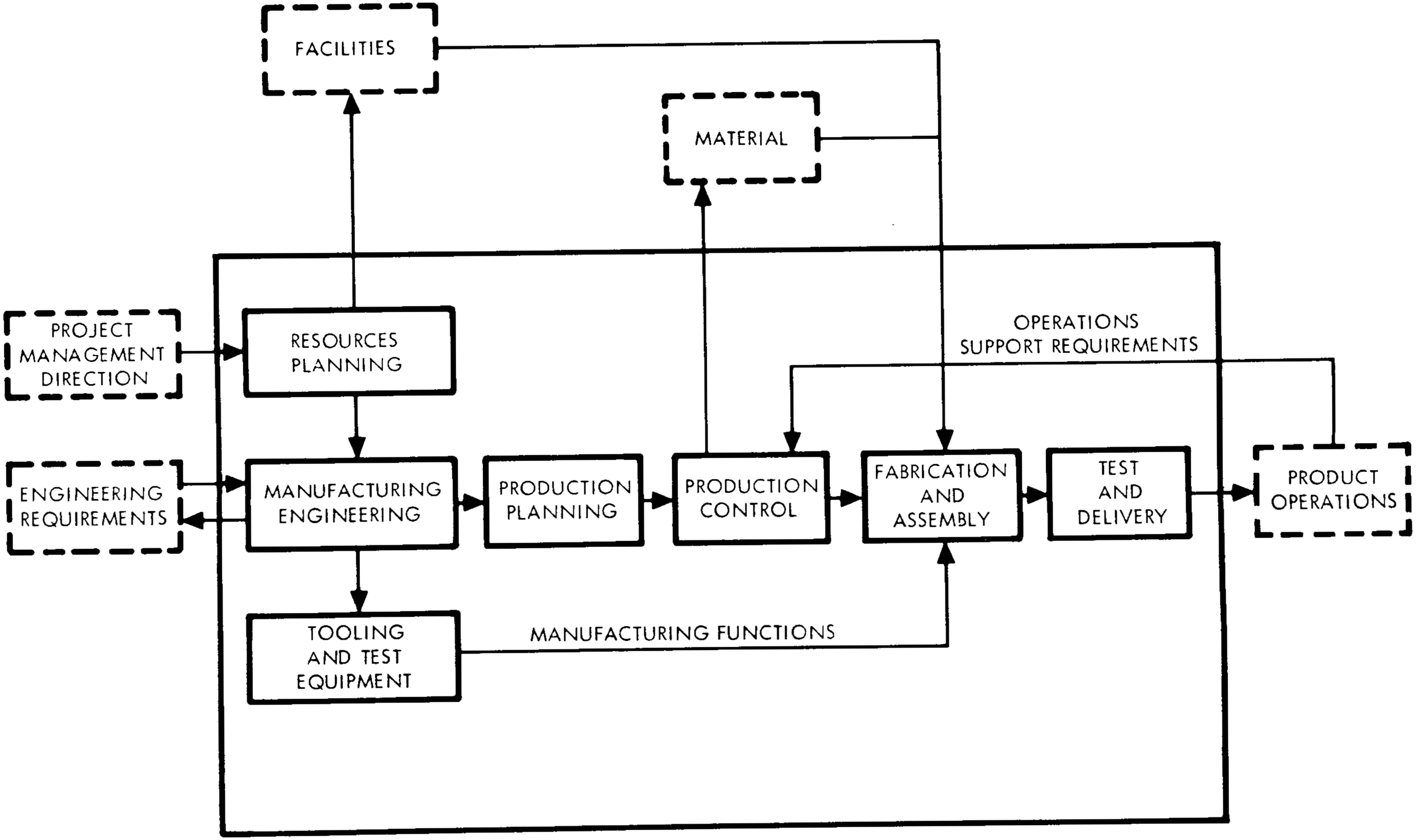


Figure 3-1. Manufacturing Process

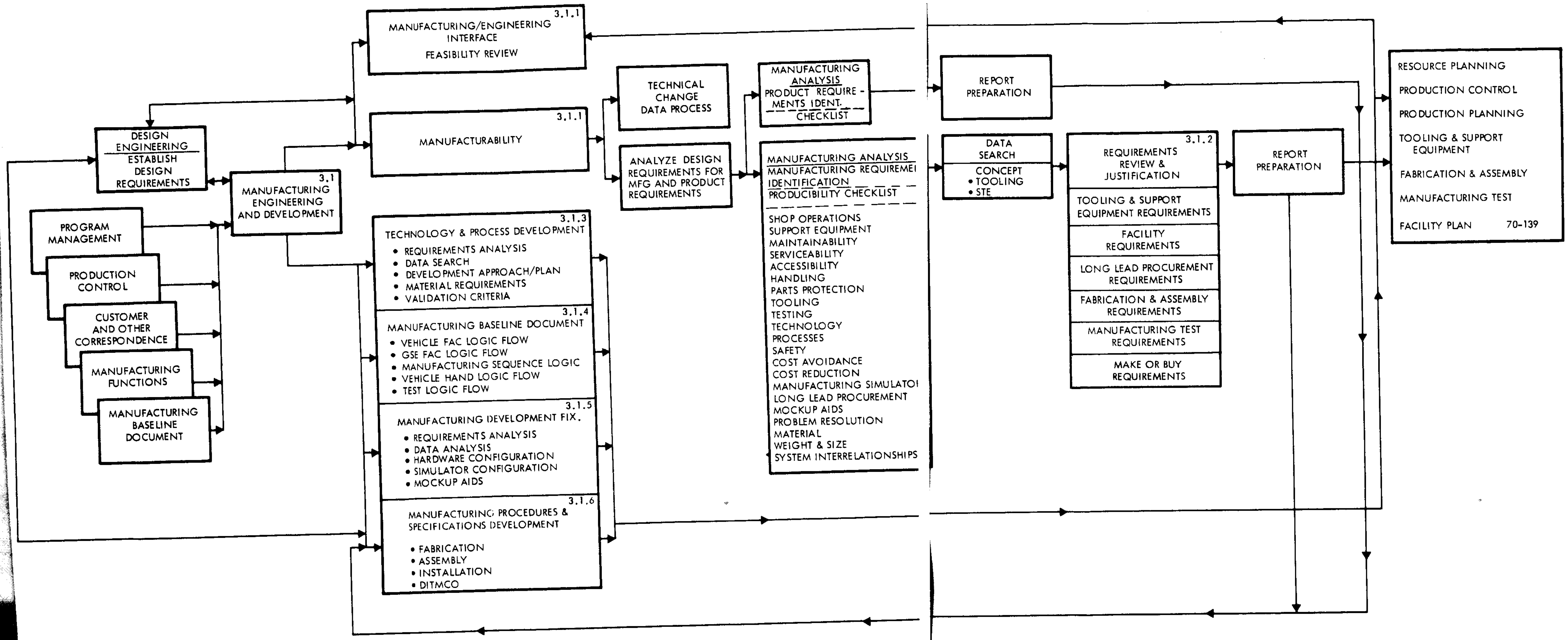


Figure 3-2. Manufacturing Engineering and Development Functional Logic Flow

The work-station area support consists of hardware, software, test equipment, tooling, skills, and facility items required for fabrication, assembly, and installation operations. During Phase C, Manufacturing Engineering will prepare logic flows, review advanced engineering data, and analyze manufacturing work-station requirements with the concerned functions (engineering, facilities, industrial engineering, etc.).

Make-or-buy decisions will be initiated early in the system and design engineering phases and continue throughout the production phase. Manufacturing Engineering will recommend to a make-or-buy committee the items or products to be manufactured and the items or products to be purchased. The committee will act on these recommendations after analysis of total contractor resources, outside resources, and product requirements.

During Phase C, Manufacturing Engineering will identify requirements for manufacturing test equipment based on review and analysis of MSS hardware and GSE test requirements determined by Engineering. The required special test equipment (STE) will be designed and produced by Manufacturing as nondeliverable support equipment.

Manufacturing Technology and Processes

Standard manufacturing technology and processes will be used wherever practicable in the manufacturing process. Manufacturing Engineering, however, will identify and develop new and revised manufacturing techniques and processes that will enhance MSS program quality, reliability, and cost performance.

Manufacturing Baseline Document

During Phase C, Manufacturing Engineering will use design engineering data as they become available to prepare a baseline document for use by functional manufacturing groups in planning activities. The baseline document will contain product and facility logic flows, describe the disciplines and functional interfaces necessary for efficient production effort, and identify major manufacturing product and facility milestones, gross standards, and logic sequence flows for testing, major tools, facilities, STE, handling equipment, parts protection equipment, contract end-items, and prospective make-or-buy items. It also will provide the data necessary for costing, manpower and machine loading, master index scheduling, work-station identification, and fabrication and inspection record book preparation. An engineering drawing number identification system will be established in the baseline document as an aid to the development of a product plan. This numbering system will provide a standard basis for part identification and terminology throughout the program.

Manufacturing Development Fixtures

Requirements for manufacturing development fixtures will be established early in Phase C. These fixtures will be designed to resolve configuration issues before final production drawing release to minimize design hardware and tooling changes. Ground test vehicles will be utilized as development fixtures when schedules permit.

Fabrication Assembly and Installation Procedures

Manufacturing Engineering will prepare procedures for fabrication, assembly, and installation of MSS products. These procedures will detail, in sequence, the manufacturing steps necessary to meet engineering and manufacturing requirements.

3.3.2 RESOURCES PLANNING

The Space Division will develop, implement, and administer effective resource planning of all manufacturing effort. Resource planning consists of cost administration, cost estimating, budget control, analysis of resources, and development of mechanized systems.

Management reports will be compiled to meet program management, work package, functional area, and department requirements. Month-end reports will be prepared to show the performance of each work package. All variances that are not within acceptable limits will be identified and explained.

Performance measurement reports will be generated to measure the cost and schedule effectiveness of the department, as well as the program or product end-item. These reports will compare actual hours with earned standard hours to derive a productivity index.

Mechanized computer systems will provide operational control, management information, schedule status, and, when feasible, operating documentation such as job cards and material requisitions.

Business systems used by manufacturing for cost, schedule, performance measurements, and reporting will be in accordance with the principles established in the MSS Program master plan (SD 71-225).

3.3.3 PRODUCTION CONTROL

A production control function will be provided to coordinate the hardware-related aspects of the MSS Program. Production control encompasses the interrelated functions of production programming, inventory management, work-in-process control, and production property control.

The functions of production control are fundamental to MSS manufacturing operations; they assure the orderly and economic flow of work and materials, response to changes, total accountability of production inventories and properties, and constant surveillance of production support status. The functions of production control are shown in Figure 3-3. The flow of production control through the scheduling, hardware handling, and control, and reporting processes is shown in Figure 3-4.

Production Programming

Production programming includes the functions of scheduling, change control, order control, and machine and work station loading. It establishes precise production program guidelines, authorization, and time phasing and maintains operational surveillance.

Scheduling

To assure integrated production program support at all levels, all MSS hardware effort will be precisely controlled by schedule. Every part, tool, assembly, or component will be identified to its next supporting need by the manufacturing building sequence with a direct, currently maintained calendar relationship. This relationship extends into the pre-engineering release area, using the manufacturing baseline as the fundamental point of departure, and is developed from a system of production family groupings as index or control points for manageability. The program master schedule will be the basis for development of schedules for manufacturing operations.

Change Control

Change control will be conducted in accordance with the configuration management requirements established in the MSS Program Master Plan, SD 71-225. Manufacturing Operations will participate in change control activities as follows:

1. Assist Engineering in the technical definition by providing manufacturability analysis.

2. Analyze and take action to minimize the potential impact of proposed changes on material procurement, tooling, work in process, field operations, spares, etc.

3. Develop alternative approaches and workaround plans where necessary.

4. Plan and track the actual incorporation of approved changes.

INPUTS		OUTPUTS
	PRODUCTION PROGRAMMING	
PROGRAM SCHEDULES	SCHEDULING	SCHEDULES, DIRECTIVES
CHANGE CONTROL BOARD	CHANGE CONTROL	CHANGE ANALYSIS, IMPLEMENTATION
BLUEPRINTS, PLANNING MASTERS	ORDER CONTROL	ORDER RELEASE, LOCATION & STATUS
WORK ORDERS, STANDARDS	MACHINE/WORK STATION LOADING	DAILY/HOURLY SCHEDULES
	INVENTORY MANAGEMENT	
ENGINEERING AND MANUFACTURING DATA	SELECTION AND PROCUREMENT	BUY REQUISITIONS
HARDWARE TO WAREHOUSE	DISTRIBUTION	HARDWARE TO USE
REQUIREMENTS BY AREA	ASSETS CONTROL	INVENTORY MANAGEMENT SYSTEM
SURPLUS ASSETS	DISPOSITION	STORE, TRANSFER, DISPOSE
	WORK-IN-PROCESS CONTROL	
WORK ORDERS, BLUEPRINTS	CONTROL STATIONS	JOB INITIATION, FOLLOW-UP
MATERIALS, COMPONENTS	STOCK ROOMS	JOBS STAGED FOR SHOP
WORK ORDERS, MATERIAL BLUEPRINTS	OUTSIDE PRODUCTION	JOBS COMPLETE TO STOCK ROOM
	PRODUCTION PROPERTY CONTROL	
TOOL AND SUPPORT EQUIPMENT REQUIREMENTS	REQUIREMENTS AND RECORDS	ACCOUNTABILITY AND CONTROL
TOOLS AND SUPPORT EQUIPMENT	PRODUCTION PROPERTY STORES	TOOLS & SUPPORT EQUIPMENT TO USE
HAND TOOLS & SUPPLIES	TOOL AND SUPPLY CONTROL STATIONS	HAND TOOLS & SUPPLIES TO USE

Figure 3-3. Production Control Functions Summary

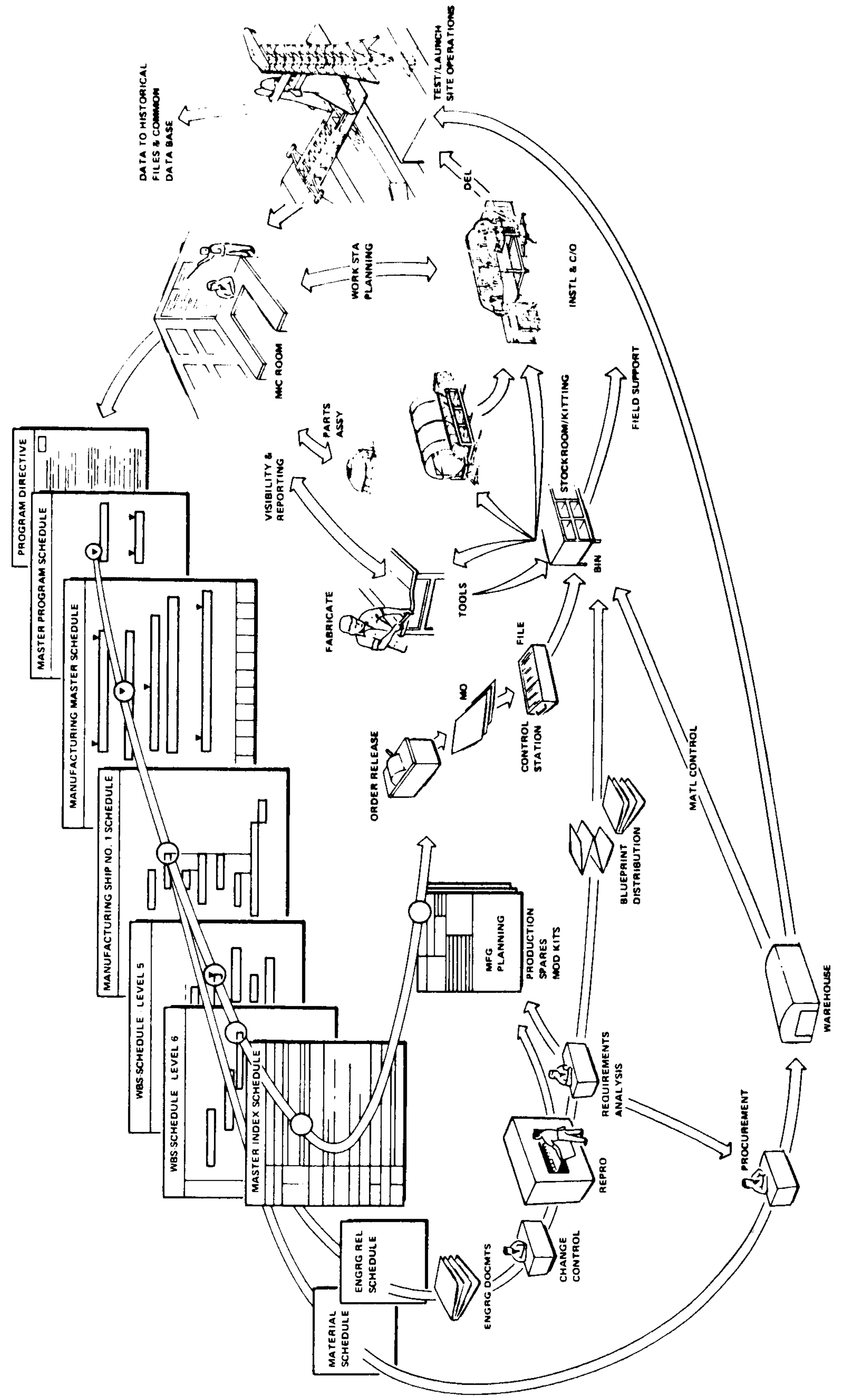


Figure 3-4. Production Control System

Order Control

The order control function includes the initiation and release of individual requisitions and manufacturing operation records for the authorization and control of individual parts, tools, and components in the manufacturing process. Each order will be scheduled, proper accounting data applied, and operations sequenced and routed as determined by production planning. Accountability release records will be maintained and current order locations and status information provided.

Order control functions on the MSS Program require an on-line, real-time computer system for program manageability. A manufacturing parts and build-tree data bank will be used to maintain a schedule index or control point correlation that provides the specific requirement schedules for all orders. Order control requirements also include the following functions:

1. Determination of economic order quantities on an item-by-item basis.

2. Maintenance of schedule discipline at the order release control point through upstream/downstream monitoring.

3. Operation of a closed-loop configuration recording system to assure that all new and changed engineering requirements are received by the proper release control point, that all such requirements are planned, scheduled, and released for manufacture, and that all work released is completed or accounted for.

Configuration Control

Based on identification and traceability requirements specified by Engineering, configuration records will be established and maintained throughout the manufacturing order system. Serial number of serial-controlled components will be recorded on authorizing transfer, installation, and removal orders, leaving a clear trail of location, history, and use. Transfer of contract end items from one major work station to another will be clearly authorized and documented through a recap and move authorization. Current configuration and any open work at that authorized transfer level will be documented on the recap and move authorization.

All necessary data from this configuration recording system will be input to the common data base. QA will review the manufacturing operation of this system to assure effectiveness of the configuration accounting and control disciplines.

Inventory Management

The Space Division will establish a system for inventory management during production of the MSS and related ground support equipment, spares, and production tooling. This system will be part of an integrated inventory management system that encompasses production, test, and logistics material from acquisition through ultimate disposition. The Manufacturing Inventory Control and Logistics Inventory Control functions will be integrated elements of the overall common data base system. Logistics inventory control requirements are defined in the Logistics Support section of this document.

Electronic data processing will be applied extensively to assure rapid response to material requirements and to provide complete visibility of all contractually acquired assets in the inventory, including a record of transactions that affect inventory, to assure maximum utilization of available material and avoidance of shortages.

Work-In-Process Control

Work-in-process control will be established to support day-to-day manufacturing operations. This process will utilize control stations and stockrooms to assure that all required physical resources are available at each work station to meet schedule and work requirements. Outside production resources will be utilized when required.

Control Stations

Current open-requirements documentation will be filed and maintained by control stations, and each job will be processed according to schedule. Progress and problems on each job will be reported to the order location and status system on a current basis. Shortages, discrepant materials or parts, necessary reworks, and all other anomalies to the smooth functioning of the production process in the area of physical resources will be reported and coordinated by the control stations.

Stock Rooms

The stock room will screen all incoming and returned materials, parts, and components for proper identification, documentation, and evidence of quality acceptance. As directed by the control station, the stock room will prepare materials and kit and stage all jobs for the shops to assure that required physical resources are available at each work station on schedule.

Outside Production

Outside production resources will be utilized to accommodate temporary overloads or to take advantage of specialized capabilities.

Production Property Control

Production property control will be established to maintain accountability and surveillance of production property, which includes special tooling, special test equipment, and general-purpose tools and test equipment. Production property control will provide record control, production property stores (readiness maintenance), and general tooling services. It will assure that production property required to support manufacturing operations is available at assigned work stations to meet schedule and work requirements.

3.3.4 PRODUCTION PLANNING

A production planning function will be established to process and translate engineering orders, drawings, process specifications, and logistics information into detailed manufacturing instructions consistent with the manufacturing baseline document. Figure 3-5 defines this process. Information instructions will be prepared for production release in the form of manufacturing orders, tool orders, and material requisitions. These work authorizing documents provide production control and tooling accountability data and permanent quality assurance records in addition to step-by-step work instructions.

Production planning will utilize engineering documentation to establish a manufacturing order priority in relation to the manufacturing baseline document and the manufacturing schedule.

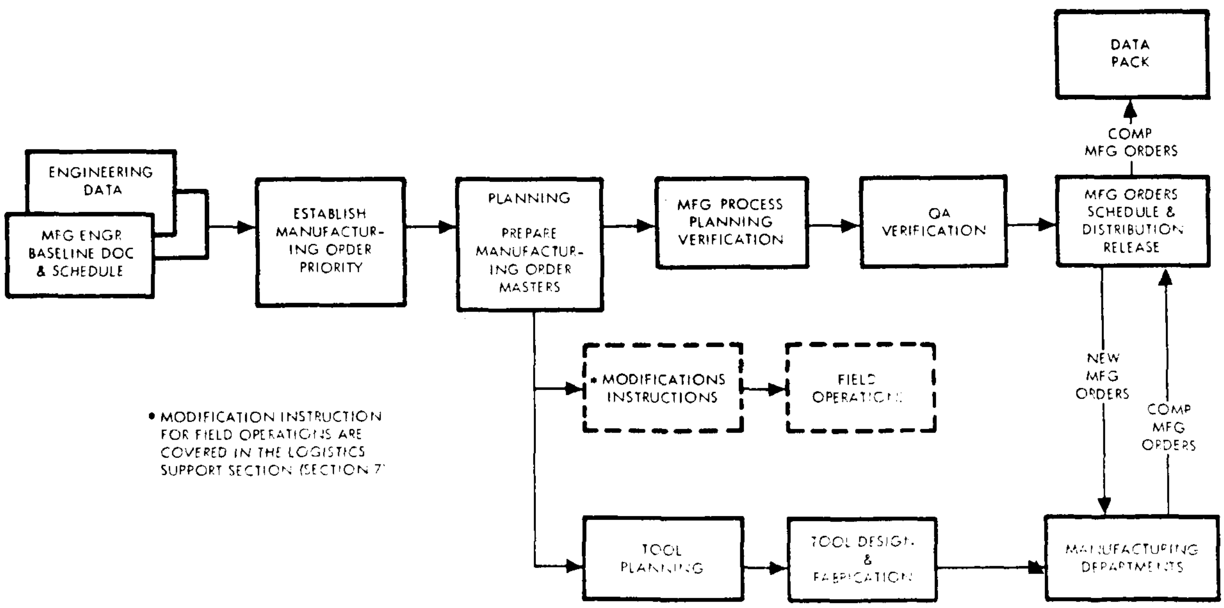


Figure 3-5. Production Planning Flow Logic

3.3.5 SPECIAL-PURPOSE TOOLING AND TEST EQUIPMENT

The Space Division will assure that special-purpose tooling and test equipment is identified, planned, scheduled, and fabricated to support manufacturing requirements for fabrication, testing, processing, handling, and protection of space station end-products.

Special-Purpose Tooling

Special tools such as jigs, dies, fixtures, templates, master layouts, molds, gauges, and manufacturing aids will be required to assure dimensional accuracy, repeatability, and uniformity of fabrication.

To provide the tooling required for optimum low-cost fabrication of the space station and its supporting equipment, available tooling and equipment will be utilized wherever feasible.

Specialized tooling is defined as that which, without substantial modification or alteration, is limited to the production of supplies or parts or the performance of services that are peculiar to the requirements of the space station. This definition does not apply to consumable small tools, general-purpose machine tools, or similar capital items. Soft and temporary tooling will be provided where sizes, low quantities, and economic considerations dictate.

Special Test Equipment (STE)

STE initiates the in-plant equipment required to manufacture or test deliverable products only to the extent that GSE is not available to meet schedule requirements or manufacturing in-process test criteria.

Special test equipment will consist of specialized electrical, electronic, hydraulic, pneumatic, mechanical, or other equipment, which, without modification or alteration, are limited to the testing of particular items or parts or in the performance of particular services. The term special test equipment includes all components of any assemblies of such equipment, but does not include consumable property, special tooling, or buildings, nonseverable structures (except foundations and similar improvements necessary for the installation of STE), general or special machine tools, or similar capital items.

3.3.6 FABRICATION, ASSEMBLY, AND INSTALLATION

Fabrication, assembly, and installation operations will be conducted in accordance with the manufacturing baseline document, production planning and control directions, and schedule milestones to produce quality products at minimum cost. Manufacturing methods and processes will be similar to those established on related aerospace programs. Compliance with engineering dimensional tolerances, design, material, process specifications, and other applicable requirements will be verified by the quality assurance function.

The Space Division will utilize the same manufacturing processes and controls for all deliverable flight hardware and ground support equipment. Each primary element will be broken down into details, subassemblies, and assemblies to determine the optimum manufacturing sequence, material requirements, and inspection points.

Fabrication

Standard-sized parts will be fabricated using conventional aerospace machine tools and processes. Large detail components will be fabricated using numerically controlled machine tools, high-capacity press brakes, and stretch form machines, high-energy forming, and large-scale chemical milling and surface treating processing equipment.

Assembly

Subassembly and assembly of primary structures will be accomplished by welding, bonding, or mechanical methods. Optimum quality and integrity will be built into the structure by the use of proven automatic equipment. Certification of qualified personnel will be required for those personnel performing bonding, welding, and critical operations.

The MSS structures will be assembled in the vertical position for all circumferential welding, where practical, to take advantage of the even gravitational forces and reduce the need for additional tooling and aids for maintaining alignment of the structure as well as the utilization of existing tools and facilities.

Secondary structure and final system installations will be accomplished in the horizontal position because of the longitudinal floor concepts.

Installation

Secondary structures and subsystems will be installed using installation methods and techniques developed on other aerospace programs as applicable, and as determined through manufacturability analysis with engineering. Critical subsystems will be installed in a clean-room atmosphere as defined by engineering requirements. Typical manufacturing assembly sequences for the space station systems are shown in Figures 3-6, 3-7, 3-8, and 3-9.

Manufacturing Development Fixtures and Systems Mockups

All subsystem mockups and development fixtures will utilize the flight-type ground test structures to determine pneumatic and hydraulic tubing and

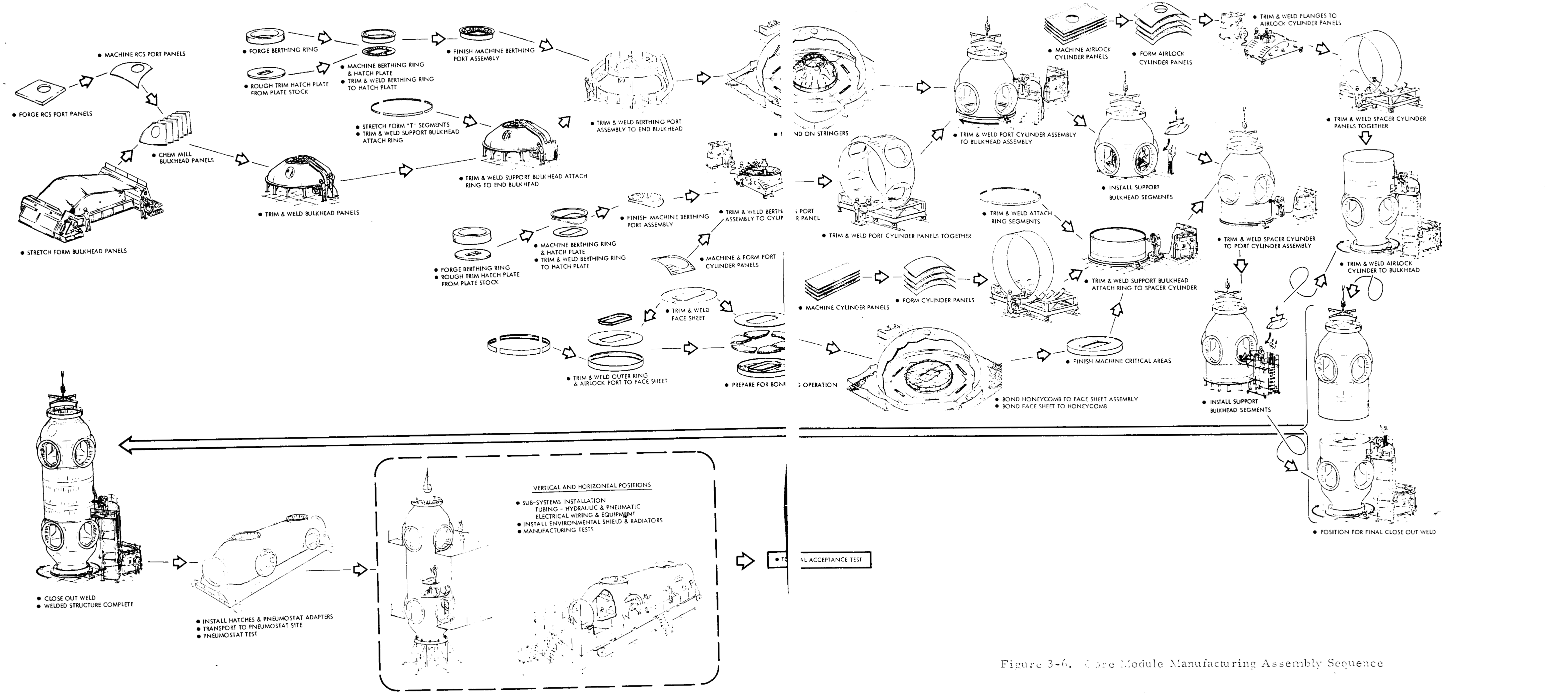


Figure 3-6. Core Module Manufacturing Assembly Sequence

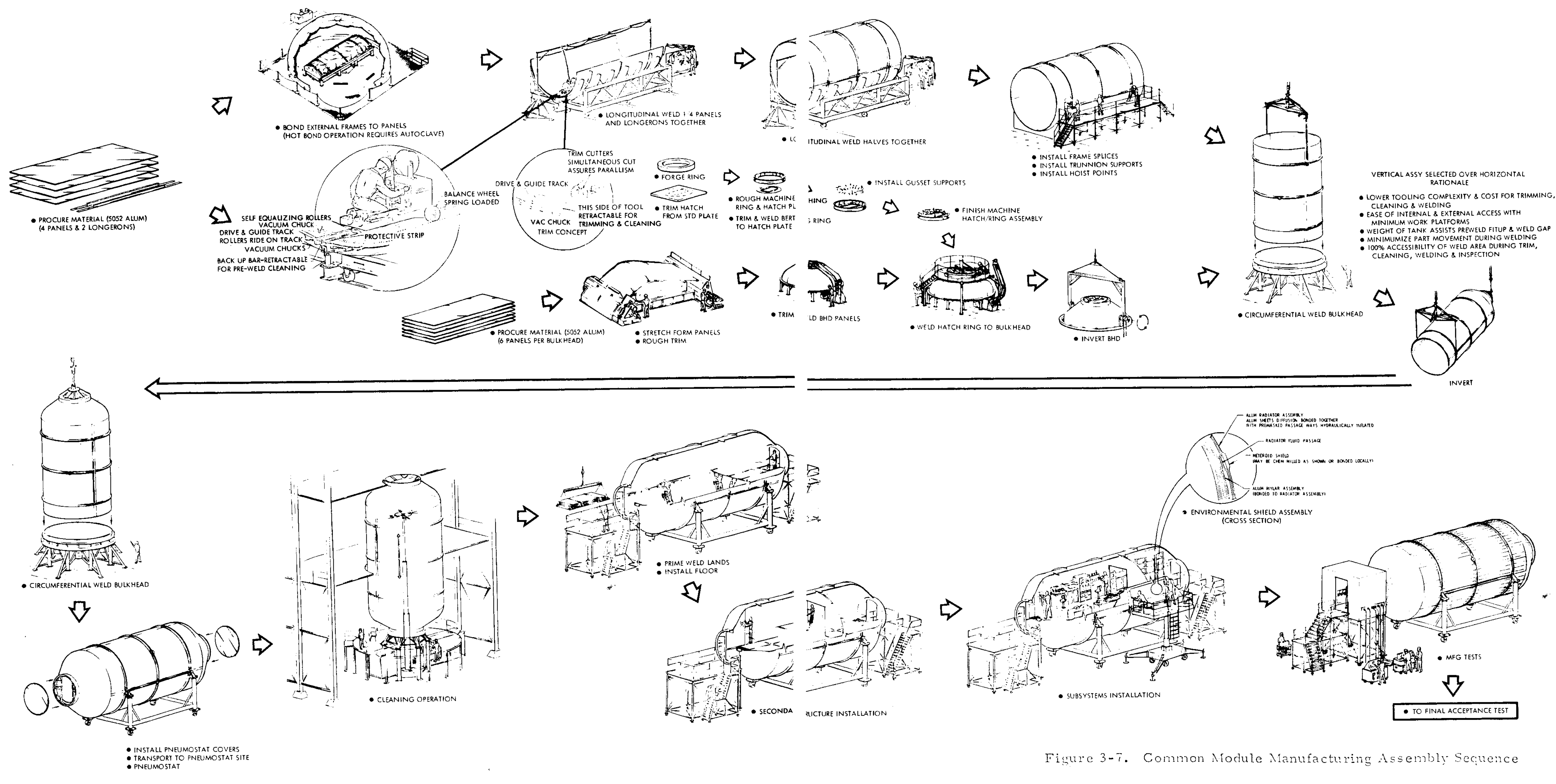


Figure 3-7. Common Module Manufacturing Assembly Sequence

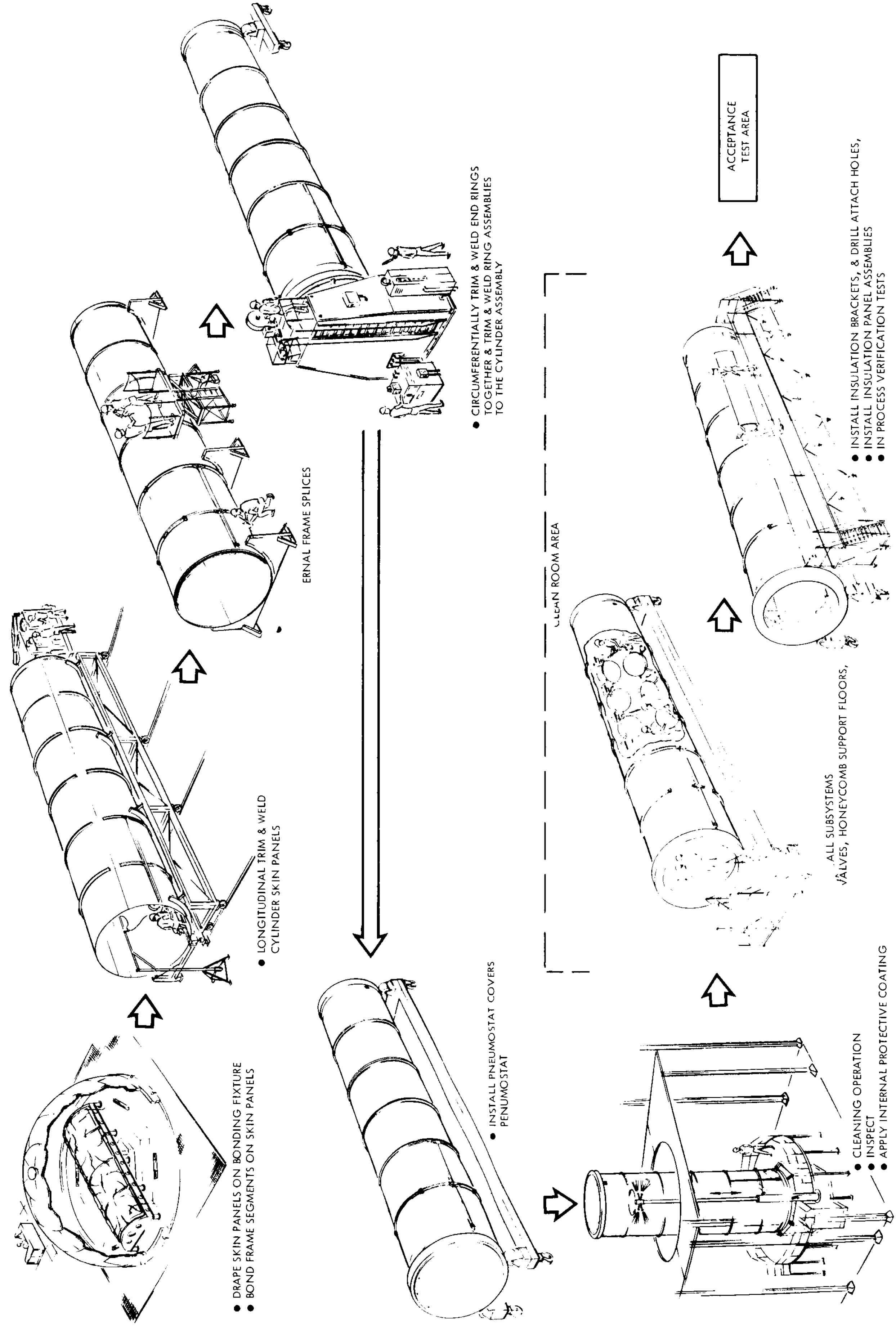


Figure 3-8. Power Module Manufacturing Assembly Sequence

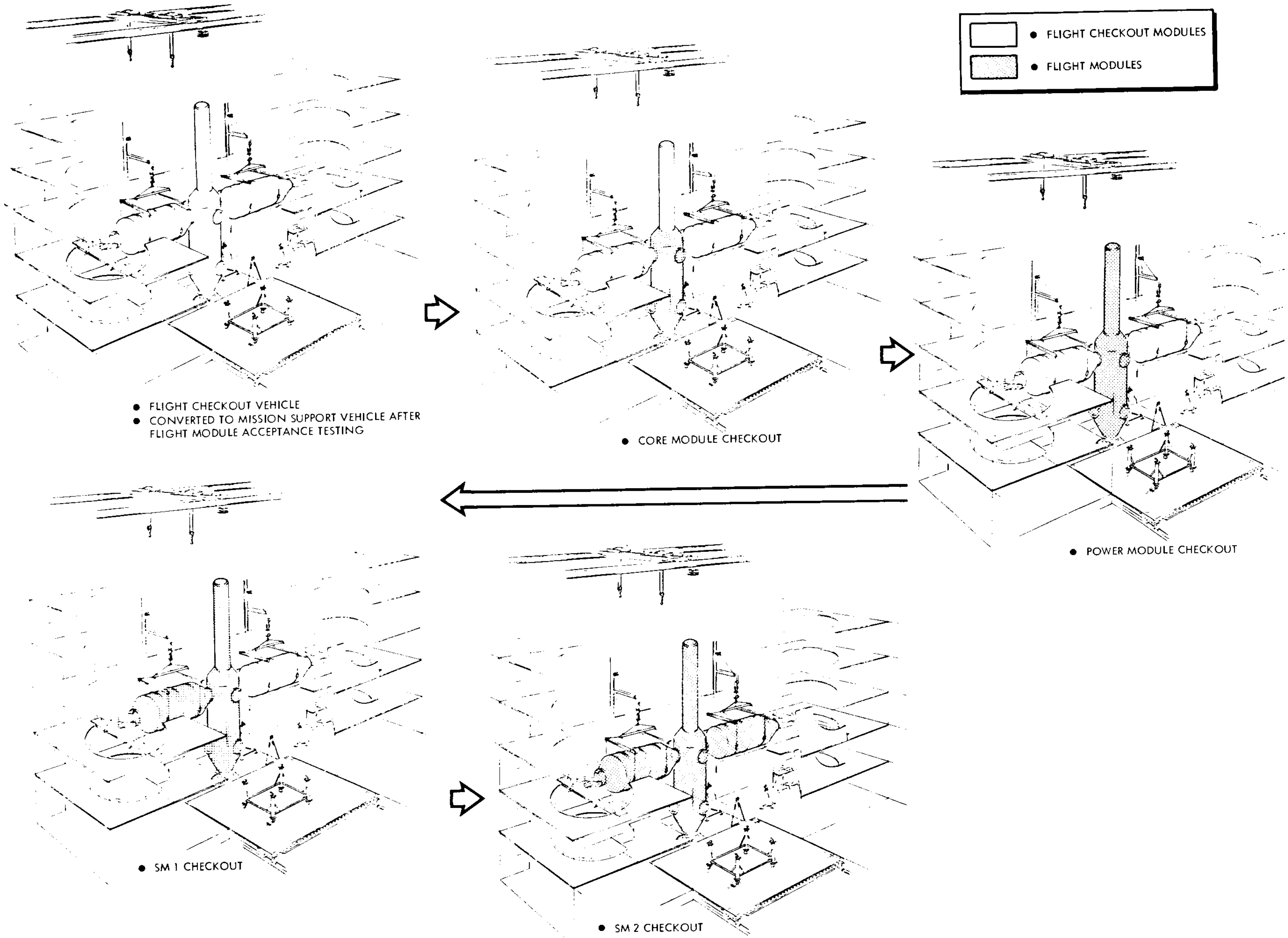


Figure 3-9. Flight Acceptance Test Sequence

wire harness configurations wherever test schedules permit. Manufacturing development fixtures will be provided where phasing of ground test vehicles indicate their inability to support the fabrication and assembly schedules. Simulated components and consoles will be identical in appearance and size to the actual items except that they will not be functional nor contain any internal components or equipment. Only the required interfaces, walls, partitions, doorways, ducting, etc., will be installed. The configuration of the interconnecting systems (wire harnesses and tubing runs) between the various consoles and components will be fitted to size and shape and will be the primary visible method to determine each actual run configuration. The actual flight runs will be fabricated to these approved configurations.

Ground Support Equipment

Ground support equipment includes deliverable nonflight elements or devices required to inspect, test, adjust, transport, safeguard, record, store, actuate, or otherwise perform a function in support of a flight vehicle or article during (1) acceptance tests at the manufacturing site after final assembly, (2) prelaunch and launch operations, (3) major development tests such as propulsion tests and environmental tests, (4) transportation of the flight vehicle or article, and (5) mission operations. This includes equipment required to support GSE, and bench maintenance activities. GSE will be fabricated in the same manner as flight and other end item hardware.

3.3.7 IN-PROCESS VERIFICATION

The Space Division will conduct tests to verify that each system is within the engineering design and performance requirements defined in the contract end-item specification, and to demonstrate that each system is functionally acceptable for delivery. Test sequencing is shown in Figure 3-8.

All in-process verification testing will utilize data from the common data base for procedures and data requirements, and will input test results from built-in test points to the common data base for later reference through the production configuration control data terminals described in Section 3.3.1.

In-Process Test Planning

Test planning will support engineering in establishing the test requirements, identifying support resources, and developing and maintaining a test program baseline for all subsequent test planning activities. Based on review of the in-process test requirements, Test Planning will provide operational criteria to Engineering for consideration in development of the test requirements. These requirements provide the basis for estimating checkout and acceptance test spans for use in supporting the master program schedule activity and the subordinate master test schedule. The master test schedule is the controlling schedule within manufacturing test operations, and identifies the test time spans and the associated milestones for all major checkout activities.

Engineering test requirements and the master test schedule for the baseline Modular Space Station configuration will be used to identify the support equipment requirements and need dates for the test program.

Test Procedure Development

Test procedures will be prepared to support the engineering test requirements for acceptance testing and in-process confidence level testing (common data base element). These procedures provide the detailed step-by-step sequences to be performed in specific tests.

The preparation and release of the test procedures will be phased in accordance with the need dates established from the master test schedule.

The scope of each in-process test will be established to provide technical guidelines for preparation of the final procedure. The scope establishes the test depth, basic sequencing, and support requirements for each test.

Acceptance Test Plan Development

The test procedures developed in support of engineering requirements and acceptance specifications, the master test schedule, and initial span times, will form the basis of the acceptance test plan. This plan defines the operational time-phasing, test logic sequence, and operational need dates for supporting software and test equipment required for acceptance testing.

Checkout Operations

Checkout operations will include all tests conducted to verify compliance with design and test requirements. These tests will be performed to establish field readiness at the highest possible level. The total checkout will be divided into four phases to be conducted at the manufacturing and/or launch site as shown in Figure 2-4, Section 2. The phases are:

1. Subassembly, assembly, and final assembly tests
2. End-to-end tests of each subassembly
3. Integrated system test and crew equipment integration
4. Checkout tests and preparation of the equipment for final packaging and delivery and acceptance by NASA.

The core module, power module, and station modules SM-1 and SM-2 will undergo all four phases at the manufacturing site utilizing the flight module checkout vehicle. SM-3, SM-4, and the cargo modules will undergo Phases 1 and 2 at the manufacturing site, then be shipped to the launch site where Phase 3 will be conducted utilizing the MSV, followed by a modified Phase 4, and NASA acceptance.

3.3.8 DELIVERY

Prior to delivery, the Space Division will accomplish all closeout operations, including final modifications, closeout of documents in preparation for final acceptance, accumulation of all loose equipment and the ground support equipment required for shipping, and satisfying environmental requirements for shipping. The equipment for shipping will be inspected, cleaned, fit-checked, and proof-loaded before the delivery date.

Requirements for protection against corrosion, contamination, and physical damage during handling, transport, and storage will be met, and a shipping plan prepared for the orderly delivery of all end-item hardware to the launch site.

3.3.9 MANUFACTURING PROBLEM CONSIDERATIONS

The manufacturing methods and techniques selected for MSS fabrication, assembly, and installation are within present technology and it is not anticipated that any significant technical problem will be encountered. Typical management and scheduling problems related to procurement, subcontractor support, and imposed configuration changes require planning and prompt management action. The Space Division system for resolving technological, procurement, and scheduling problems places emphasis on engineering and manufacturing interfaces, early identification, assessment, and solution.

Application of proposed solutions for methods and processes will be developed by manufacturing technology, which will research new methods, processes, and procedures before applying them to production.

In the event of problems related to procurement and schedule, the Space Division will make trade studies of various alternatives and develop solutions for management approval.

4. GROUND SUPPORT EQUIPMENT

4.1 PURPOSE

This section identifies the ground support equipment (GSE) required for the test and flight elements of the MSS Program.

4.2 SCOPE

This section covers all the equipment needed to meet the functional requirements for:

Acceptance

Assembly and installation

In-process verification

Servicing and support

Transportation and handling

Protective covers

This equipment will be utilized for development (including qualification), manufacturing, acceptance, prelaunch and launch operations, and maintenance and refurbishment activities of the MSS elements. Equipment will be located at the manufacturing, development, acceptance, and launch sites. The various types of GSE will be distributed as shown in Table 4-1.

Wherever possible, discrete items of ground support equipment are identified in terms of the projected usage at one or more of the specific sites listed in Table 4-1. Each item identified will be defined during Phase C/D of the MSS Program.

To describe the major GSE functional requirements, each site was analyzed in terms of the functions performed at that site. After identifying all major functional requirements, the total was minimized by considering common usage at a particular site and the actual transfer of equipment from other sites because of program phasing requirements.

Table 4-1. Premission Ground Support Equipment Distribution

Functional Requirements	Site			
	Development	Manufacturing	Acceptance	Launch and Refurbishment
Acceptance		X	X	X
Assembly and Installation		X		X
In-process Verification	X	X		
Servicing and Support	X	X	X	X
Transportation and Handling	X	X	X	X

Level 5 functional requirements can be identified only by listing the combined requirements generated at Level 7. Table 4-2 identifies all the major GSE functional requirements in terms of site and function usage which was established at Level 7.

Table 4-2. Summary of Major GSE Functional Requirements

Level 5* / Level 6 / Level 7 — GSE Item	Manufacture Site: Fabrication & Struct Ass'y	Manufacture Site: Final Ass'y & Checkout	Development Site: Static Environment	Development Site: Dynamic Environment	Development Site: Acoustic Environment	Development Site: Therm-Vac Environment	Development Site: Integration Tests	Development Site: Flight Demonstration	Accept Site: Comp. Assembly & Subsystem Accept.	Accept Site: Flight Module Acceptance	Accept Site: Delivery	Launch Site: Recurring Inspection	Launch Site: Flight Module Acceptance	Launch Site: Prelaunch & Launch Maint. & Refurb.	Total
1.0 Structural & Mechanical Subsystem Checkout Requirements															
1.1 Primary Structure Requirements															
1.1.1 Spreader Bars and Slings	6	6					6			PL	PL		PL	6	24
1.1.2 Adapter Ring	4						4		PL	PL	PL		PL	4	12
1.1.3 Rotational Transporter	6	3							PL						3
1.1.4 Highway Transporter (universal)	6	CI					CI			CI	CI			CI	6
1.1.5 Module Entry Platform (universal)	6	6									4	4		4	24
1.1.6 Module Protective Covers (set)	6	CI					CI			CI	CI			CI	6
1.1.7 Weight and Balance Fixture														1	1
1.1.8 Storage Dolly	4													4	8
1.2 Secondary Structure Requirements (none identified)															
1.3 Environmental Shield Requirements (none identified)															
1.4 Berthing Requirements															
1.4.1 Berthing Port Interface Checkout Stand		1										1			2
1.4.2 Orbiter Docking Simulator		1										1			2
1.5 General Purpose Lab Furnishings Requirement (none identified)															
2.0 Environmental Control Life Support Subsystem Checkout Requirements															
2.1 Gaseous Storage Requirements															
2.1.1 Oxygen Fill, Drain, Purge and Leak Test Unit		1					1		1	PL	PL		TI		3
2.1.2 Hydrogen Fill, Drain, Purge and Leak Test Unit		1					1		1	PL	PL		TI		3
2.1.3 Nitrogen Fill, Drain, Purge and Leak Test Unit		1					1		1	PL	PL		TI		3
2.2 CO_2 Management Requirements															
2.2.1 CO_2 Management Assembly Purge Unit		1					1		1	PL	PL		TI		3
2.2.2 Water Fill, Drain, Purge and Leak Test Unit		1					1		1	PL	PL		TI		3
2.3 Atmospheric Control Requirements															
2.3.1 Conditioned Air Supply Unit		2					2			PL	PL		TI		4
2.4 Thermal Control Requirements															
2.4.1 Internal Coolant Fill, Drain Purge and Leak Test Unit		1					1		1	PL	PL		TI		3
2.4.2 Ground Coolant Cart (external loop)		2					3		1	PL			TI		6

Legend:
PL = Previously listed
CI = Caravan item
TI = Transferred item
TBD = To be determined

*X.0 = Level 5
X.1 = Level 6
X.1.1 = Level 7

Table 4-2. Summary of Major GSE Functional Requirements (Cont)

GSE Item (Level 5*, Level 6, Level 7)	Manufacture Site: Fabrication & Struct Ass'y	Manufacture Site: Final Ass'y & Checkout	Development Site: Static Environment	Development Site: Dynamic Environment	Development Site: Acoustic Environment	Development Site: Therm-Vac Environment	Development Site: Integration Tests	Development Site: Flight Demonstration	Accept Site: Comp. Assembly & Subsystem Accept.	Accept Site: Flight Module Acceptance	Accept Site: Delivery	Launch Site: Recurring Inspection	Launch Site: Flight Module Acceptance	Launch Site: Prelaunch & Launch Maint. & Refurb.	Total
2.4.3 External Coolant Fill, Drain Purge and Leak Test Unit									1					1	2
2.4.4 Radiator Protective Covers (set)		9					CI			CI	CI		CI	CI	9
2.5 Water Management Requirements															
2.5.1 Cleaning & Sterilization Unit		1							1		1			1	4
2.6 Waste Management Requirements (none identified)															
2.7 Hygiene Requirements (none identified)															
2.8 Special Life Support Requirements (none identified)															
3.0 Electrical Power Subsystem Checkout Requirements															
3.1 Primary Power Generation Requirements															
3.1.1 Solar Array Simulator		1					1		1	PL			TI		3
3.1.2 Solar Array Support Stand									1				1		2
3.1.3 Solar Array Handling Device									1				1		2
3.2 Secondary Power Generation Requirements (none identified)															
3.3 Energy Storage Requirements															
3.3.1 Water Fill, Drain, Purge, and Leak Test Unit		PL					PL		PL	PL	PL		PL		-
3.4 Power Conditioning Requirements															
3.4.1 Electrical Load Bank		1					1		1	PL			1		4
3.4.2 Conditioned Power Supply		1					1		3	PL			1		6
3.5 Distribution, Control and Wiring Requirements															
3.5.1 Universal Test Equipment		1							TBD				1		2
3.6 Lighting Requirements (none identified)															
4.0 Guidance & Control Subsystem Checkout Requirements															
4.1 Inertial Reference Requirements															
4.1.1 Rate Table - IMU									1						1
4.1.2 Alignment Optics - IMU									1						1
4.2 Optical Reference Requirements															
4.2.1 Cryogenic Horizon Simulator									1						1
4.2.2 Star Simulator									1						1
4.3 RCS Electronics Requirements															
4.3.1 RCS Engine Simulators									1						1

Legend:
PL = Previosuly listed
CI = Caravan item
TI = Transferred item
TBD = To be determined

*X.0 = Level 5
X.1 = Level 6
X.1.1 = Level 7

Table 4-2. Summary of Major GSE Functional Requirements (Cont)

Level 5* / Level 6 / Level 7 — GSE Item	Manufacture Site		Development Site						Accept Site			Launch Site			Total
	Fabrication & Struct Ass'y	Final Ass'y & Checkout	Static Environment	Dynamic Environment	Acoustic Environment	Therm-Vac Environment	Integration Tests	Flight Demonstration	Comp. Assembly & Subsystem Accept.	Flight Module Acceptance	Delivery	Recurring Inspection	Flight Module Acceptance	Prelaunch & Launch Maint. & Refurb.	
4.4 Momentum Exchange Requirements															
4.4.1 Large Rate Table									1						1
4.5 Computer Software Requirements (none identified)															
5.0 Reaction Control Subsystem Checkout Requirements															
5.1 Propellant Accumulators Requirements															
5.1.1 Oxygen Fill, Drain, Purge and Leak Test Unit		PL					PL		1	PL	PL		PL		1
5.1.2 Hydrogen Fill, Drain, Purge and Leak Test Unit		PL					PL		1	PL	PL		PL		1
5.2 Propellant Feed Control Requirements															
5.2.1 RCS Functional Checkout Unit									1						1
5.3 Engines															
5.3.1 Engine Protection Covers (set)		CI							16		CI				16
6.0 Information Subsystem Checkout Requirements															
6.1 Data Processing Requirements															
6.1.1 C/C&M Input Unit		1							1						2
6.1.2 Modulation Processor Test Set		1							1						2
6.1.3 Universal Test Equipment		PL							TBD						TBD
6.2 Command/Control and Monitor Requirements															
6.3 External Communications Requirements															
6.3.1 K-band Test Set		1					1		1	PL			TI		3
6.3.2 S-band Test Set		1					1		1	PL			TI		3
6.3.3 VHF Test Set		1					1		1	PL			TI		3
6.4 Internal Communications Requirements															
6.4.1 TV Test Set		1					1		1				TI		3
6.4.2 Digital Voice-Phone Test Set		1					1		1				TI		3
6.5 Software Requirements (none identified)															
7.0 Crew Habitability Subsystem Checkout Requirements															
7.1 Personal Equipment Requirements (none identified)															
7.2 General/Emergency Equipment Requirements (none identified)															

Legend:
PL = Previously listed
CI = Caravan item
TI = Transferred item
TBD = To be determined

*X.0 = Level 5
X.1 = Level 6
X.1.1 = Level 7

Table 4-2. Summary of Major GSE Functional Requirements (Cont)

Level 5* / Level 6 / Level 7 / GSE Item	Manufacture Site		Development Site						Accept Site			Launch Site			
	Fabrication & Struct Ass'y	Final Ass'y & Checkout	Static Environment	Dynamic Environment	Acoustic Environment	Therm-Vac Environment	Integration Tests	Flight Demonstration	Comp Assembly & Subsystem Accept.	Flight Module Acceptance	Delivery	Recurring Inspection	Flight Module Acceptance	Prelaunch & Launch Maint. & Refurb.	Total
7.3 Furnishings (none identified)															
7.4 Recreation/Exercise/Crew Care Requirements															
7.4.1 Medical/Dental Transportation Container									8					PL	8
7.5 Food Management Requirements															
7.5.1 Food Transportation Container									16					PL	16

Legend:
PL = Previously listed
CI = Caravan item
TI = Transferred item
TBD = To be determined.

*X.0 = Level 5
X.1 = Level 6
X.1.1 = Level 7

4.3 GROUND SUPPORT EQUIPMENT CONSIDERATIONS

The major considerations in establishing the types of ground support equipment were flight article manufacturing, acceptance, and verification flows and the application of the integrated ground operations guidelines in such a way as to minimize the variety of GSE. Other considerations included mission success, cost avoidance of hazard to ground and flight personnel, safety of mission equipment, and the support life of 10 years.

4.3.1 DEFINITION OF GSE

Ground support equipment is that equipment required for in-process verification (including stimuli and simulation), assembly and installation, acceptance, servicing, and support, and transportation and handling.

GSE is further defined as such equipment located at more than one site; equipment required at only one site is not general in design or usage and is therefore classified as special test, facility, or capital equipment.

Some items required for transportation and handling, for instance, are common at government-base and industrial-base facilities and need not be designed especially for this project. In this case, they may be classified as material handling equipment, laboratory equipment, etc. A third requirement is that GSE must be designed (or created) specifically for this project. The exception to this is GSE which is usable from other projects and can be transferred into the GSE inventory of this project. Maximum common use of GSE between current and past projects is a design goal.

4.3.2 FLIGHT HARDWARE FLOW

Initial Flight Hardware Flow

Manufacturing and acceptance testing will interface in the conventional manner through subsystem acceptance. Subsystem is defined as the level before installation in the complete system.

Subsystem acceptance normally will be accomplished at a supplier's facility. When this is not possible, subsystem acceptance will be at the Space Division. The subsystems will next be installed in the appropriate flight element (module) and the first four flight modules will be acceptance-tested in the flight module checkout vehicle. The remaining flight modules will be acceptance-tested in the mission support vehicle at KSC. The flight module will be delivered to the prelaunch location, checked, serviced, and installed in the orbiter cargo bay. It will then be moved to the launch pad for launch readiness verification and launch.

Resupply Flight Hardware Flow

The manufacturing and acceptance sequence will be performed in the same manner for hardware and flight elements to be resupplied to the MSS. Flight hardware and software will be checked for compatibility on the mission support vehicle, receive flight readiness verification, serviced, and packaged for launch at the prelaunch location. It will then be transferred to the launch site for loading of time-critical items.

4.3.3 INTEGRATED GROUND OPERATIONS GUIDELINES

The integrated ground operations guidelines include those for qualification, acceptance, and operations. These guidelines are discussed in detail in Section 2.

Qualification Guidelines

The qualification test disciplines are integrated into the total test program. Each component of every program element will be analyzed for qualification requirements and a program qualification matrix established. The matrix will define the specific test or analysis requirements for the qualification of each subsystem at the component or subassembly level. The qualification matrix will be developed concurrent with the design phase and will be based on a realistic assessment of mission performance requirements for the item under consideration, criticality, historical data, and the effectiveness of the test and the test sequences to which it will be subjected. The development and acceptance test activities are expected to provide a large portion of data required to fulfill the requirements of the qualification matrix. These data will be stored in the common data base.

Acceptance Guidelines

Acceptance testing at the component and subassembly level will include suitable flight-level environments, plus a margin. Acceptance of resupply spares, experiments, or subsystem modifications will include installation and checkout in the flight module checkout vehicle (until the fourth flight module is accepted) or the mission support vehicle (for the remainder of the MSS Program).

Operations Guidelines

Subsystem status will be determined by utilization of the onboard checkout capability and universal test equipment, as applicable.

4.3.4 MINIMIZING NEW GSE

Existing GSE will be utilized to the maximum extent possible to perform the premission operations functions. Multiple use of GSE is planned. For example, series manufacturing of the modules permits the use of certain GSE in more than one location. As another example, the compatibility assessment vehicle will have multiple uses during its lifetime which utilizes the same GSE. Prototype subsystems, installed in the structural test articles (after completion of structural tests), are utilized to form the compatibility assessment vehicle; flight-type subsystems, installed in the compatibility assessment vehicle, make up the mission support vehicle. The mission support vehicle will be utilized for crew familiarization as well as mission integration test vehicle. Integrated ground operations guidelines have been developed to minimize new GSE and still accomplish the other program objectives. Acceptance tests at the component and subassembly level will include flight-level environments, plus a margin, assuring the capability to perform the mission without requiring thermal and vacuum tests of complete modules. By using the onboard checkout capability and the common data base, considerable retest and checkout operations can be eliminated at the launch site. Also, use of the same subsystem design as the shuttle, and therefore the same ground support equipment, is a design goal. The onboard checkout capability permits the use of universal test equipment, thus reducing considerably site-specialized GSE.

Universal Test Equipment

The universal test equipment (UTE) will be capable of interfacing with the space station data buses through standard interface units (SIU) to allow monitoring of MSS operations and to allow control when the onboard checkout capability cannot be used. The universal test console will be adaptable to different test programs for different subsystems by changes in the software. Displays will be primarily graphic, with some alphanumeric information; the operator may call up a variety of information to be displayed. Control will be by keyboard callup for routine control and for implementing testing changes.

Design goals for the universal test equipment are (1) modularity, (2) ease of adaptability, (3) software flexibility, (4) automated in order to minimize test personnel and operating time, (5) compact, (6) easily relocatable, (7) minimum facility support, and (8) include provisions for remote display or storage.

Major hardware elements of the universal test equipment are standard interface units, transmission system interface, universal test console, and remote display and storage.

The universal test console will check out and verify the proper operation of the equipment under test and will be sized to handle tests at all acceptance levels. The console will provide the prime control for commanding or stimulating test articles, select and receive data, process the data, and display the data. The universal test equipment will be capable of testing associated GSE and will be capable of self-test.

The UTE will utilize the designed-in ISS test or information points of each subsystem and will employ elements of the same software routines developed for the ISS. Both the UTE and ISS operations with the MSS equipment will depend on the common data base for input reference. Operational results will become a part of the common data base.

Figure 4-1 shows the various test levels and the UTE interfaces required for monitoring, stimulus, and control of subassemblies, subsystems, or modules under test.

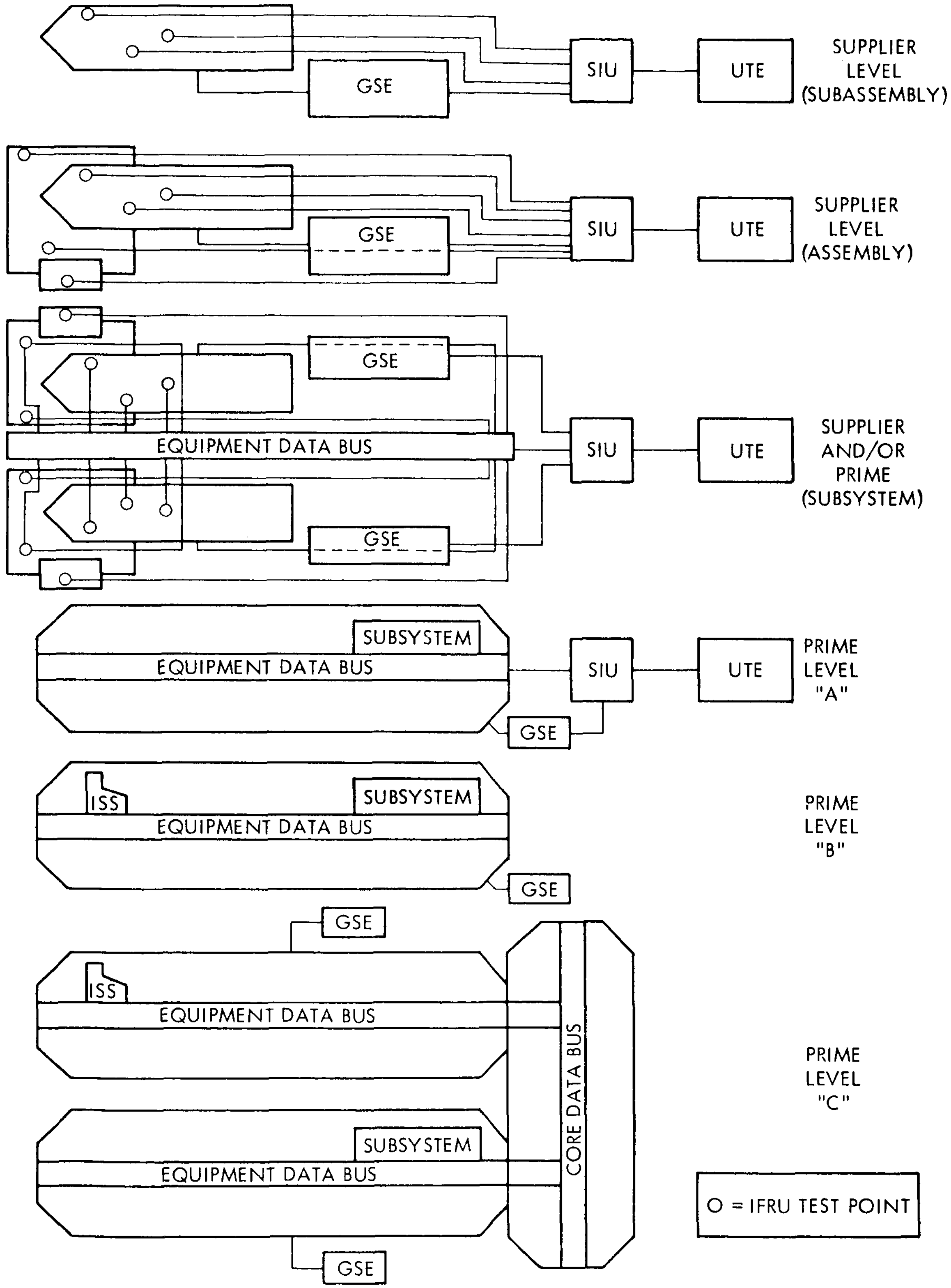


Figure 4-1. Test Levels and UTE Interfaces

4.4 MANUFACTURING SITE

The functions to be performed by Manufacturing Operations are fabrication and structural assembly, final assembly, and checkout of the MSS core, station, and power modules.

4.4.1 FABRICATION AND STRUCTURAL ASSEMBLY

The manufacture of details, components, and assemblies of the structural and mechanical subsystem will require some new equipment designs because of the unique dimensional characteristics of the test and flight modules. The equipment required for the moving of materials and structural components, however, is classified as material handling equipment. Some in-process fixtures used for form and fit functions are classified as special tooling. Proof-pressure and leak-test equipment is not expected to be used at other sites and is therefore classified as facility equipment.

Spreader bars and slings (three basic sizes) will be used to lift structural assemblies in the process of assembling the core modules, station modules, and power modules. They will also be utilized for lifting complete modules during test and prelaunch operations. These items will be capable of lifting 25,000 pounds (to assure that they can be used at all required locations) and will be proof-tested to 1.5 times their rated capacity. Proof-testing will be performed periodically throughout the manufacturing cycle of the modular space station.

Adapter rings in conjunction with an X-shaped spreader bar (Figure 4-2) will be utilized to pick up and emplace any module in the vertical position. These rings provide a load distribution function (vertical pickup mode) as well as permit easy ingress and egress when the module is positioned on any planned transport vehicle. When on the rotational transporter, the rings serve as a rotational bearing surface, permitting the entire module to revolve about the major axis. Here again, rated capacity will be 25,000 pounds and proof-testing to 1.5 times rated capacity will be performed periodically.

Module entry platforms will be required for access to the interior of each module. The design approach will rely on adjustable platforms to be able to accommodate slight variations because of the three basic module sizes (core, station, and power modules).

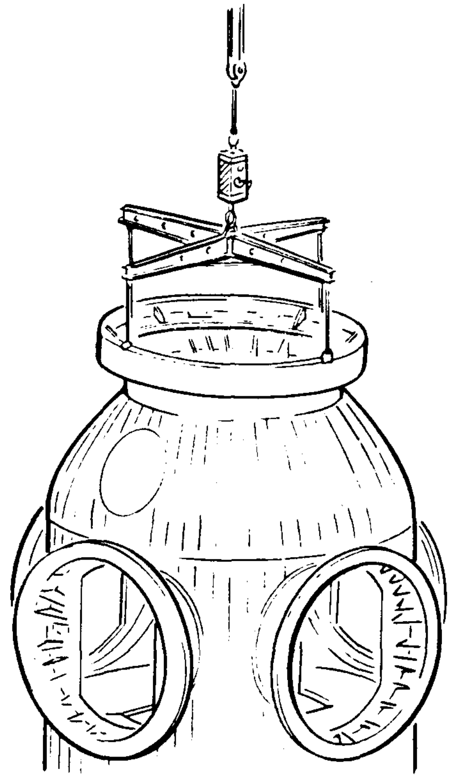


Figure 4-2. Adapter Ring and X-Shaped Spreader Bar

A rotational transporter (Figure 4-3) will be utilized during the structural assembly operations to permit the module to revolve about the major axis. This feature will enhance surface preparation, cleaning, etc.

A highway transporter will be utilized for interfacility transportation of each module. This item also will be used for transporting each flight module to the nearest air facility for air shipment to the launch site. It will travel with the module on the aircraft.

The highway transporter will be proof-tested and road-tested as a part of its acceptance test. The dimensional and proof-load test fixture will be an open-frame spool which is not classified as GSE. This fixture will proof-load the highway transporter by means of water ballast. For road tests, the fixture will simulate a typical module center-of-gravity location and be dimensionally similar. Many months prior to the initial transfer of a module from one site to another (as an example, Seal Beach to Downey), the highway transporter, with dimensional and proof-load test fixture in place, will make a trial run to verify all clearances enroute. This test fixture will be used for clearance verification at all sites and facility installations where it is deemed advisable.

A storage dolly (Figure 4-4) is envisioned for storing modules for any appreciable length of time rather than tieing up a rotational transporter or a

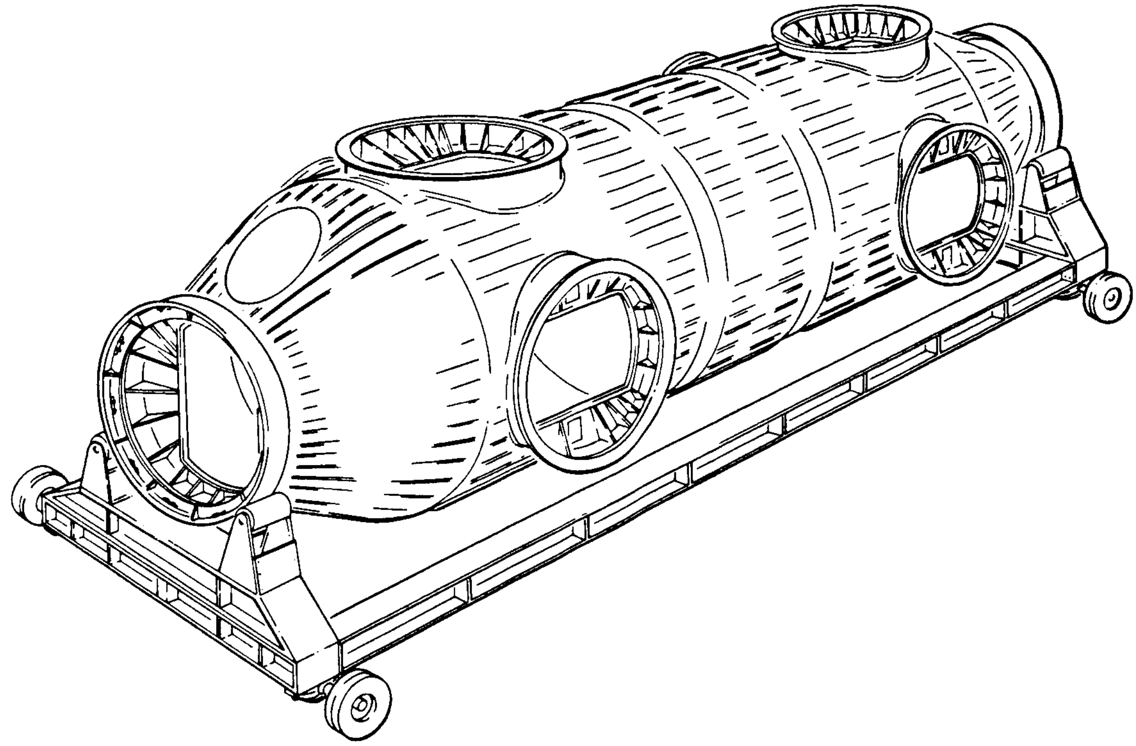


Figure 4-3. Rotational Transporter

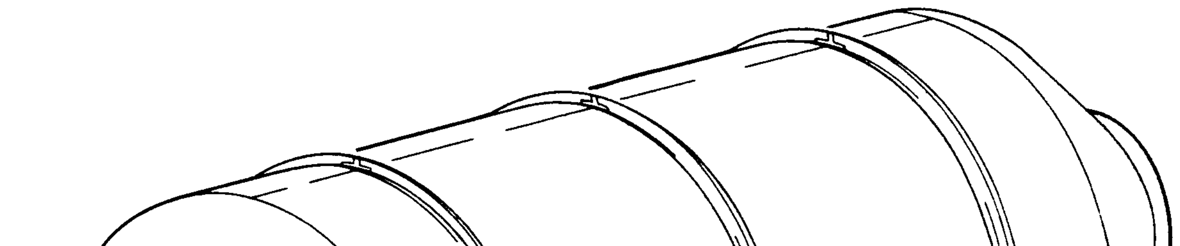


Figure 4-4. Storage Dolly

highway transporter. The simple design and inexpensive construction permits this usage with the advantage of having a wheeled vehicle for solving minor relocation problems during the storage period.

4.4.2 FINAL ASSEMBLY AND CHECKOUT

The installation of honeycomb floors, secondary structure, and subsystems will be performed in a controlled environment. To accomplish this, module entry platforms are required for access to the interior of each module. One size will accommodate the three different module sizes.

After subsystem installation is complete, preliminary checkout will establish electrical continuity, polarity, pressure systems leak and flow tests, etc. A berthing port interface checkout stand (Figure 4-5) will be utilized for these tests in conjunction with peripheral ground support equipment.

Verification of subsystem performance will be accomplished with universal test equipment. The UTE will not only have direct acquisition to the data bus of the module being tested but also will be able to control the peripheral ground support equipment. The GSE will interface with the module under test through the berthing port interface checkout stand. For those modules having the data processing assembly and the command control and monitoring assembly installed, final subsystem verification will utilize the onboard checkout capability as the primary verification tool, drawing data from and supplying data to the common data base.

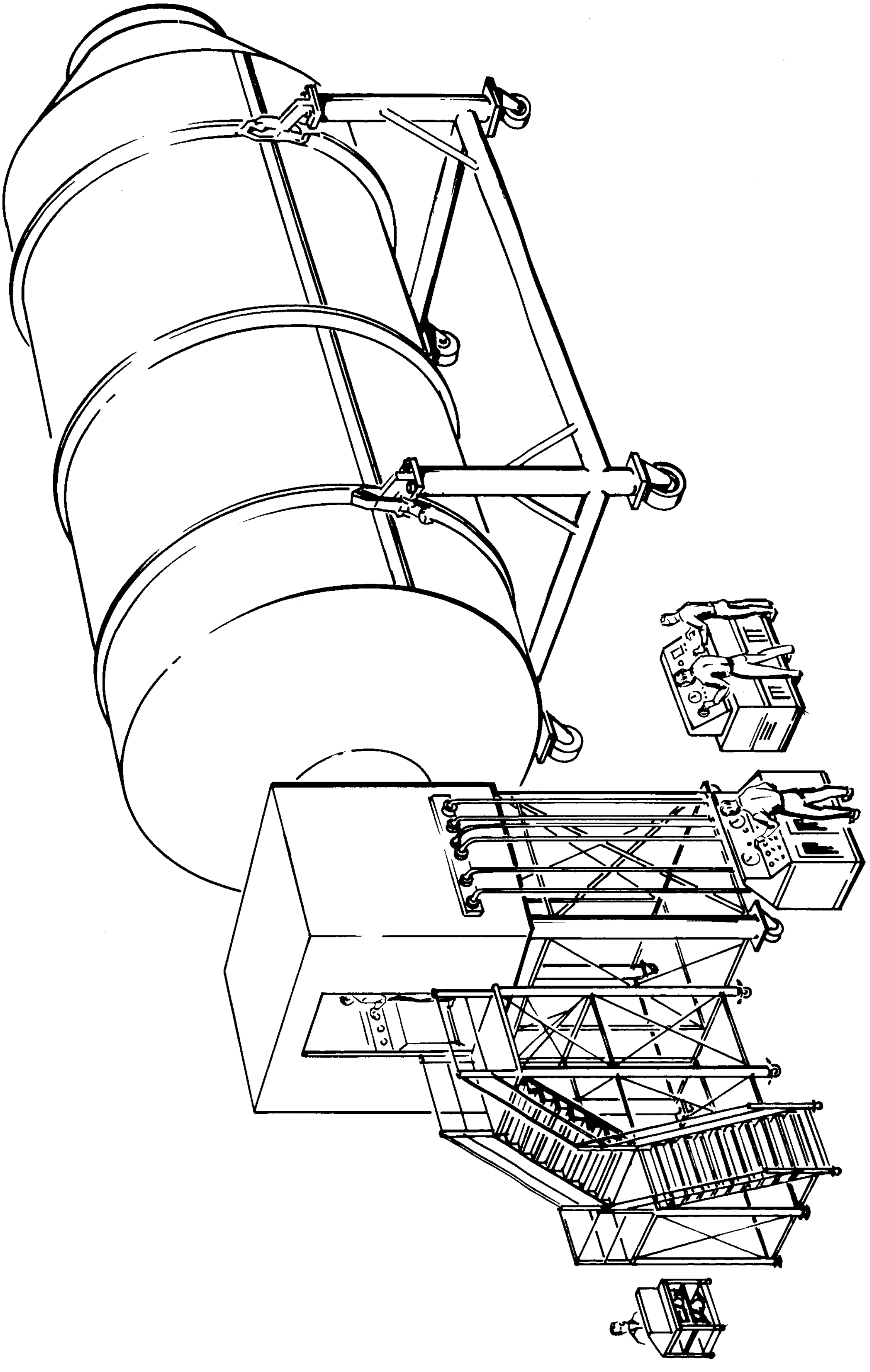


Figure 4-5. Berthing Port Interface Checkout Stand

4.5 DEVELOPMENT SITE

4.5.1 STATIC ENVIRONMENT

Structural tests will be conducted on each unique flight module (core module, station module, power module) to verify structural integrity under static conditions, for each major failure mode. Each module will consist of primary structure only (no secondary structure, no subsystems installations).

GSE needs are anticipated to be very minimal; intrafacility transportation, entry platforms, and possibly conditioned air are the only identifiable function at this time.

4.5.2 DYNAMIC ENVIRONMENT

Dynamic tests also will be conducted on each unique flight module to verify structural integrity under dynamic conditions and to determine the dynamic energy levels at the subsystem level. In addition, the frequency response characteristics and model shapes of the modules will be determined. To accomplish these objectives, each module will consist of primary structure and all secondary structure required to install floors and dummy equipment. All equipment over 50 pounds will be simulated in terms of mass and c. g. location.

GSE needs again are anticipated to be minimal; intrafacility transportation, entry platforms, and conditioned air.

4.5.3 ACOUSTIC ENVIRONMENT

The acoustic environment is anticipated to be sufficiently high to require that transmissibility and attenuation factors be verified before subsystem and assembly qualification tests and acceptance tests. To accomplish this objective, the same modules that were used for dynamic testing also will be used for acoustic tests.

GSE needs are anticipated to be the same as for the static and dynamic environments.

4.5.4 THERMAL-VACUUM ENVIRONMENT

Tests conducted in a thermal-vacuum environment are required to resolve some structural and mechanical subsystem development issues. Applying cost-avoidance principles, these issues will be resolved by testing assemblies and subassemblies as a part of this program, and testing representative modules as a part of the NASA continuing development programs (NCDP).

No major GSE needs are anticipated for this effort.

4.5.5 INTEGRATION TESTING

Verification of all subsystem functional interfaces, as well as the verification of all space station software, is a vital element of the development effort. To accomplish these objectives, the compatibility assessment vehicle will include a core module, power module, and Station Modules 1, 3, and 4. These modules will have prototypes subsystems installed and be fully capable of accomplishing the detailed test objectives with support from GSE and UTE.

Considerable GSE will be required to support this development effort.

4.5.6 FLIGHT DEMONSTRATION

Actual weightlessness or actual space environment is required for high-confifence resolution of some MSS developments. To accomplish this, functional equipment and procedures will be tested aboard late Apollo missions and Skylab II missions.

Little or no GSE is envisioned to support this effort.

4.6 ACCEPTANCE SITE

4.6.1 GENERAL

Acceptance of major hardware and software items of the MSS Program will include functional and physical configuration audits, which verify that the hardware and software have been satisfactorily developed and establish that the hardware and software have achieved the specified performance.

Acceptance tests of complete modules will demonstrate performance verification, provide assurance of operational readiness, and provide assurance that all elements of the tested module meet the established requirements.

At the conclusion of acceptance testing, the module under test will be ready for delivery to the next usage point. The acceptance site provides the following:

1. All necessary interfaces with the parts, assemblies and subsystems.
2. Complete facilities to accomplish checkout, servicing, and mechanical operations.
3. Necessary access platforms, handling, and protective devices.
4. Facilities commensurate with the type of test to be performed and with the test module's environmental requirements.
5. Necessary transportation and protective devices for subsequent delivery.

Figure 4-6 illustrates acceptance test functions and hardware flow. The figures shows that acceptance testing consists of performing the required functions at all hardware levels.

The functions required to assure operational readiness of the assembly in test are:

1. Performance - Verify design of sublevels of assembly and assembly in test, external and internal interfaces of assembly in test, and design in simulated flight environments.

2. Servicing - Application of electrical power, fluids, position (movement, alignment) to assembly in test.

3. Handling - Movement of assembly in test during the test sequence.

4. Transportation - Transporting of assembly after acceptance and packaging the assembly to be transported.

Figure 4-7 depicts delivery requirements as determined by the logical flow of items required for the modular space station and its logistic support.

The depth of testing and type of tests to be performed depend on the characteristics of the article to be tested and on the intended usage of the final product. The resolution of these factors will aid in determining the ground support equipment required to perform the acceptance functions.

4.6.2 SCOPE OF GSE REQUIRED

Acceptance testing of MSS hardware is influenced by the fact that the MSS is put into orbit unmanned, and incorporates provisions for replacement of inoperative or outdated equipment. Selected component and assembly acceptance tests will include testing at flight-level environments, plus a margin, to assure that the accepted item will perform as required in its intended operational environment.

To determine the scope of ground support equipment required, the MSS hardware has been grouped into equipment categories as listed in Table 4-3.

Table 4-3. Examples of Hardware Categories

Category	Hardware
VII	Racks, chairs, wash basins, wire cables, internal audio equipment (phones, speakers) contractors, TV monitors and cameras
VI	Fans, pumps, valve assemblies, piping, radiators
V	Storage tanks, RCS quads, fuel cells
IV	Control moment gyros, accelerometers, star trackers
III	Antennas
II	Data processing, G&C electronics, solar arrays
I	Module

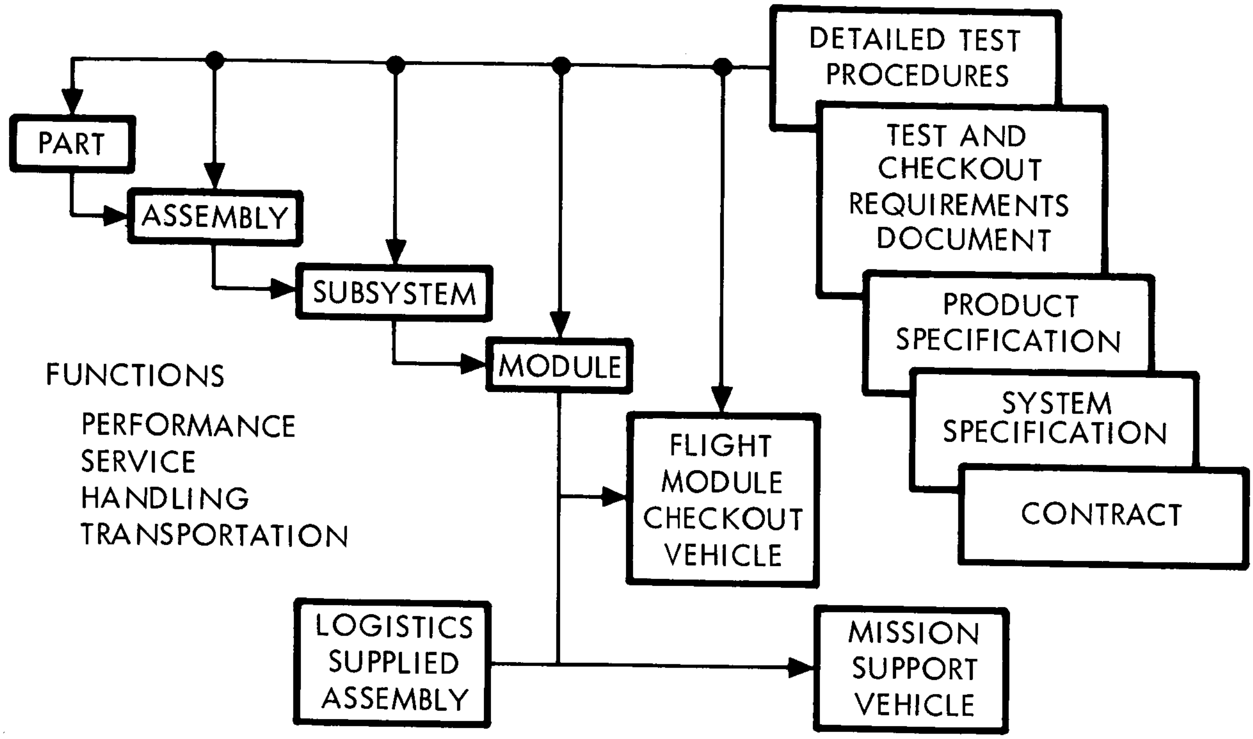


Figure 4-6. Acceptance Test Functions and Hardware Flow

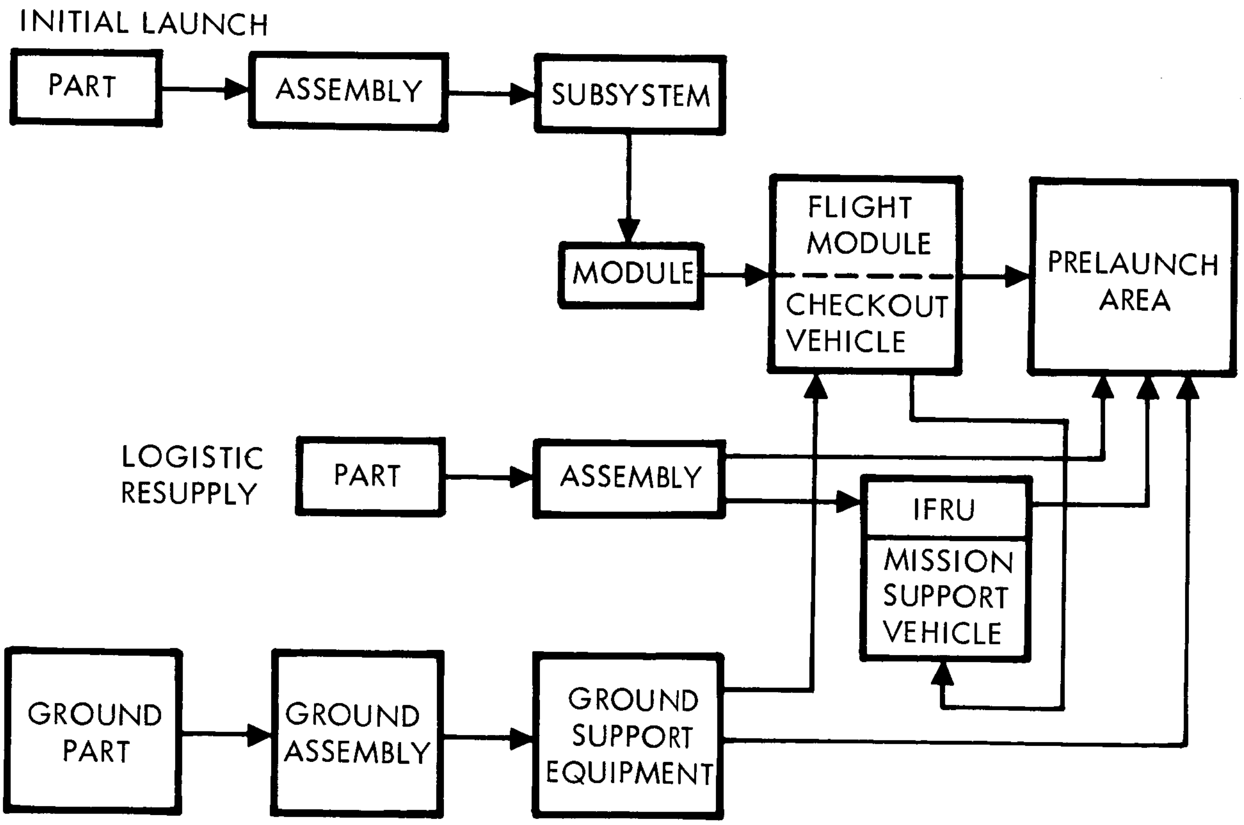


Figure 4-7. Delivery Requirements Flow Diagram

Table 4-4 shows the scope of GSE required for each hardware category. The goal is to accomplish the acceptance test functions most efficiently by utilizing minimum ground support equipment.

Table 4-4. Scope of GSE Required for Acceptance

Services to be Performed	VII	VI	V	IV	III	II	I
Physical inspection and standard laboratory testing	X						
Fluid servicing		X	X				X
Alignment							X
Ranging					X		
Electronic data processing		X	X	X	X	X	
Environmental simulation	X	X	X	X	X	X	

Category I hardware is the most complex because it consists of a complete module and will present a complex interface. The onboard data processing will be utilized to demonstrate operational performance during module testing. Fluid servicing during module acceptance testing will assure the performance status of all functional components and provide a means of rejecting the internal heat generated. Acceptance testing of Category I equipment will include a demonstration of proper alignment of optical devices and antennas. Complete integrated testing of hardware and software will be accomplished on the flight module checkout vehicle (first four flight modules) and the mission support vehicle (remaining flight modules).

Category II hardware will normally include complex electronics and a complex hardware interface, and some of the equipment presents a complex software interface. The software will be acceptance-tested utilizing electronic data processing equipment.

Category III hardware test support includes demonstration of proper frequencies, bandwidth, power capability, and ranging for antennas and radar systems. Mechanical devices for antennas as well as solar arrays must be demonstrated to be operational in the intended environment.

Category IV hardware presents a complex interface including a requirement for stimuli in the form of motion. Electronic data processing will demonstrate that proper responses are provided for the required input stimuli.

Category V hardware acceptance testing must include a demonstration that the equipment is leak-free and will withstand the expected operating pressures in the intended environment. Fluid servicing will be required for the demonstration.

Category VI hardware requires a demonstration that the equipment operates properly with the proper input, and that it is leak-free and will withstand operational pressures. Fluid servicing will be required for this testing.

Category VII hardware requires very little testing to demonstrate acceptability. Physical inspection will suffice for most of this equipment. Wiring will require demonstration of proper continuity, insulation resistance, and dielectric verification, while some devices will require laboratory testing to demonstrate proper performance.

4.6.3 INFLUENCE OF ONBOARD CHECKOUT ON ACCEPTANCE

The requirement to perform maintenance in flight requires the mechanization of onboard checkout. The OBCO function during flight requires that special provision be added to the flight hardware to facilitate this checkout. This special provision includes: (1) adequate instrumentation built into the subsystems to detect performance, and (2) the mechanization of an in-flight test system to monitor the instrumentation as it performs during normal operations and determines when the IFRU signatures are not normal. Mechanization of the in-flight test system will be encompassed within the information subsystem (ISS). The ISS, while performing its operational tasks, already has approximately 35 percent of the OBCO information required to accomplish onboard checkout.

The influence of OBCO in the acceptance of the flight hardware affects all levels of acceptance where mechanization has been included to accomplish the OBCO. The acceptance test sequence is shown in Figure 4-8.

From the engineering documentation, manufacturing is accomplished, operating checkout procedures (OCP) are developed, and test tapes are developed where automation is required. The test engineer, using the OCP, operates the test equipment which has the test tapes incorporated, to determine the performance of the equipment under test. In past programs, this process has been followed almost without variation. In the Modular Space Station Program, this procedure will be modified to the extent that the OCP's must be compatible with the OBCO function and will be verified first by means of the UTE (subsystems) and then by the OBCO (systems).

ISS Mechanization

The mechanization concept for the ISS is shown in Figure 4-9. This figure shows that the primary interface with the ISS is an item of equipment which has been identified as a remote acquisition control unit (RACU). The RACU interfaces with the central data processor through a double-bus concept (command and response) which in turn interfaces with the command/control and monitoring assembly. Three groupings of RACU and equipment under test are possible: (1) the RACU is built into each in-flight replaceable unit (IFRU) and becomes part of that assembly, (2) the RACU services a group of IFRU of a given subsystem, and (3) the RACU is placed in a central location and services several IFRU's. In each case, a RACU is required which multiplexes all data from preconditioned instrumentation points, performs the multiplexing and analog-to-digital (A/D) conversion, and provides the data to a central bus. The RACU also provides decoding and command pulses for stimuli and switching purposes in the IFRU.

The IFRU therefore becomes the major hardware item of interest to the OBCO function. Adequate signals must be made available for determining its status during operations. This capability then becomes a performance parameter and must be verified during acceptance. This means the designer of the hardware must provide meaningful test points during the design phase and prove he can check the item as part of acceptance.

From a GSE standpoint, this interface allows standarization of the design of ground equipment where complex data processing is required.

Software Impact

Probably the largest single impact of OBCO to acceptance is in the area of software and its preparation. Historically, software has been a major contributor to checkout equipment, often contributing to over one-half the cost. A major problem of the past has been the inability to apply the checkout program established during the subsystem development phase to the acceptance test of the completed assembly. Because the interface with the ISS is now a standard RACU, and because it is required for acceptance testing at the IFRU level, the software used in the development phase can be reassembled from the common data base into completed MSS Program software the same way that hardware is assembled into a modular space station. This software can then be edited and used for inflight checkout.

Data Flow

During the acceptance phase, there is a requirement for the data coming from the modular space station and its subsystems to be used by the suppliers, prime contractors, and NASA. Specifically, the supplier is

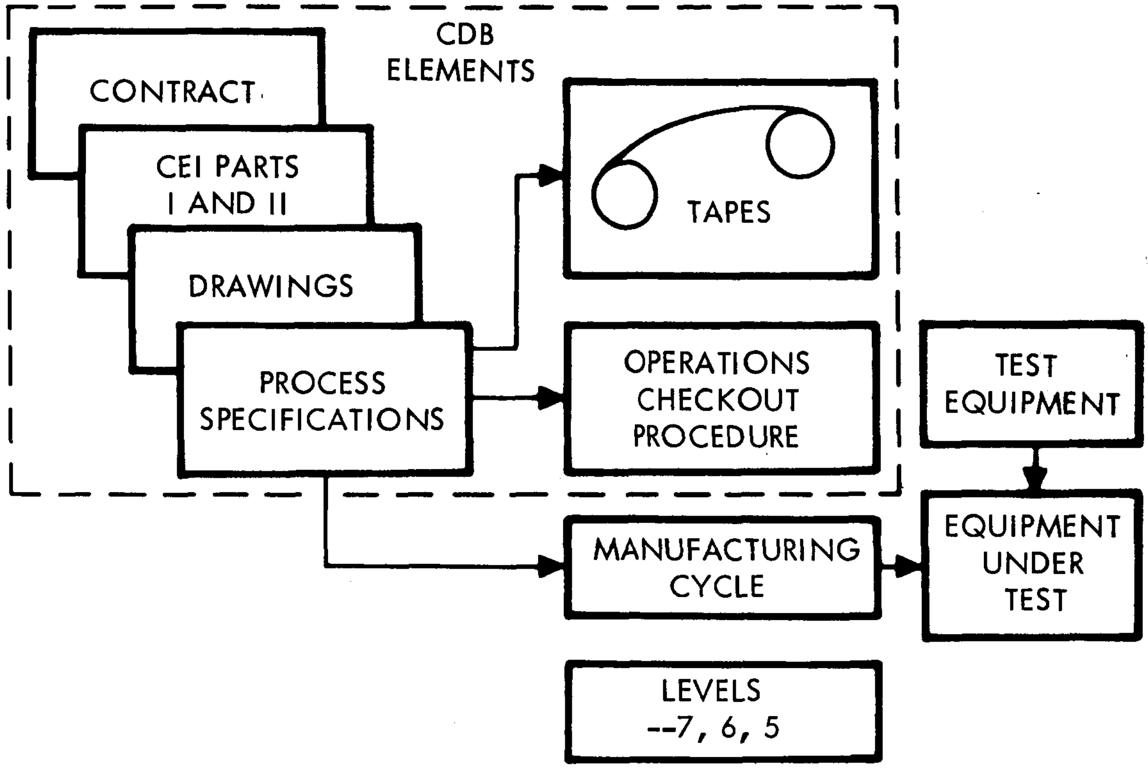


Figure 4-8. Typical Acceptance Test Sequence

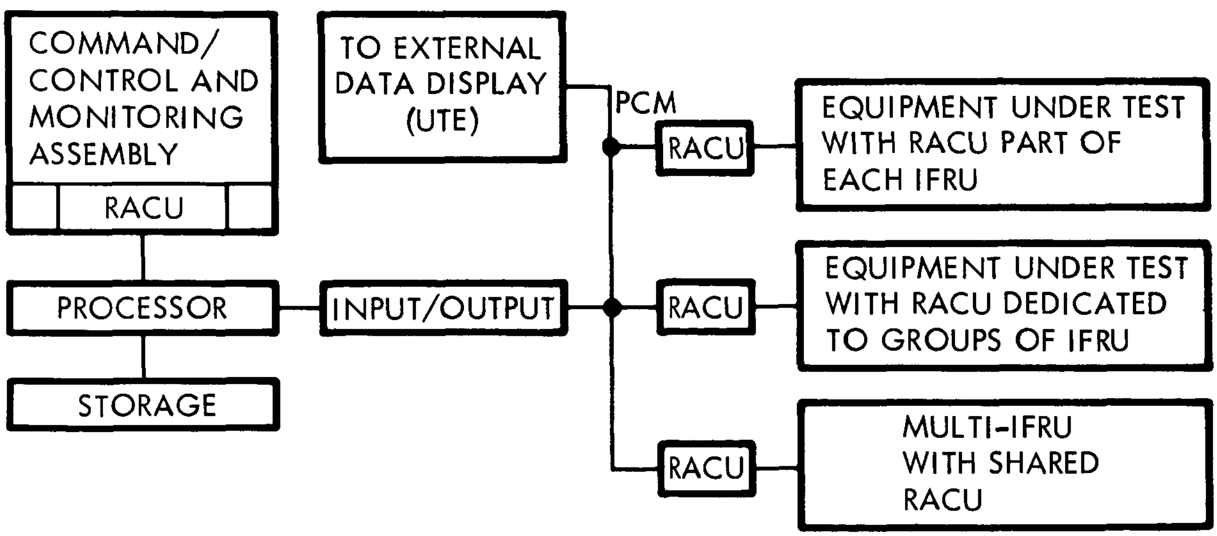


Figure 4-9. ISS Mechanization Concept

interested in how his equipment performed when interfacing with other equipment. The prime contractor has a contract responsibility to assure that NASA is getting the product which meets the system specification. To fulfill the many requirements from these sources, data bases must be established and maintained. By defining all the data requirements at the beginning of a program and building the data base starting at the IFRU supplier, all data users can be satisfied. The basic unit for data base buildup is the IFRU with its instrumentation points.

The format that must be developed for the common data base and ISS can be used to identify, sort, and track all data from its original testing sources. As the data are collected from the various sources and built into the common data base, specific numbers and tolerances will be available from which judgments and trends can be established. This type of data is essential for maintenance action long after the original assembly lines have closed.

Acceptance Sequence

The final acceptance sequence is shown in Figure 4-10.

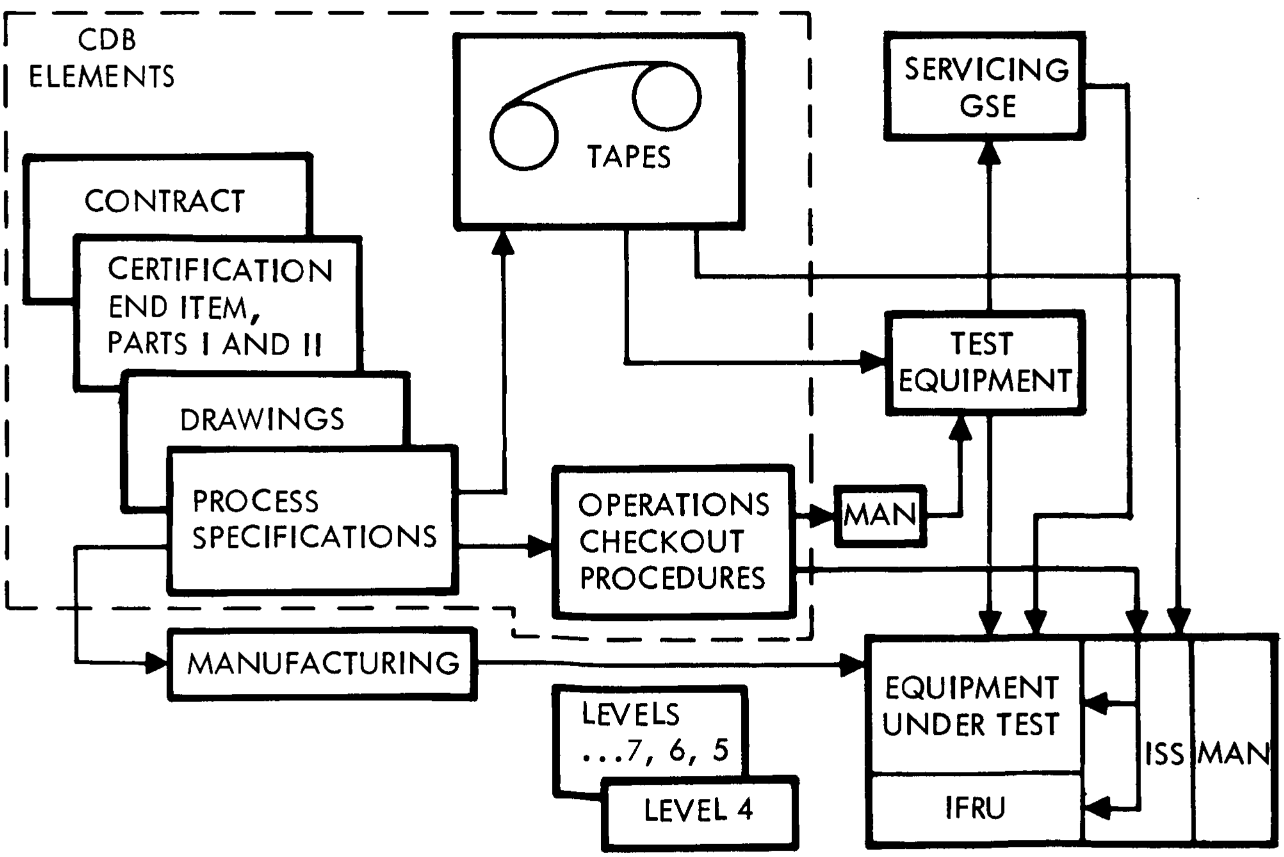


Figure 4-10. Final Acceptance Sequence

This figure takes the typical sequence flow and expands it to show the alterations required for final acceptance. The basic difference and primary influence of OBCO is shown here where the checkout responsibility now shifts into the module space station and the ISS is used as the control center. The tapes used in this checkout are an integration of those built up during the Level 7, 6, and 5 testing and stored in the common data base. The external test equipment will still be required; however, it will receive its data from the internal data distribution bus. Because the primary mode of control has shifted to inside the modular space station, the external test equipment cannot command the checkout but will serve as a monitor for the display of data to the many parties responsible for equipment function. The external test equipment will have the ability to command testing only when the ISS is not functioning (i. e., before the ISS is installed, during periods when ISS is being debugged, etc.). This external test equipment is a combination of GSE and UTE.

4.6.4 ACCEPTANCE TEST LOCATIONS

Table 4-5 lists hardware categories versus locations for performing the acceptance testing.

Each category of hardware may be acceptance-tested at the supplier's facility, at the prime contractor's facility, at a government facility, or at a facility from the private sector. Each hardware category must be evaluated in more detail to determine the optimum location for performing the acceptance test.

Some criteria for determining optimum test locations are (1) availability of test equipment, (2) availability of personnel skills, (3) minimization of test time, (4) availability of interfacing equipment, (5) availability of proper test facility, and (6) minimization of rework time, if required.

Studies were performed to determine the GSE approach for the various categories of flight hardware. Table 4-6 shows the results of the study with the selected methods indicated.

It is recognized from the studies (Tables 4-5 and 4-6) that some deviations will be required; however, these tables show the general approach to be applied with details to be supplied during Phase C.

4.6.5 COMPONENTS, ASSEMBLIES, AND SUBSYSTEMS ACCEPTANCE

Cost Considerations

In past programs, more of the cost of acceptance has gone for operation and maintenance than for development, fabrication, procurement, and installation of the ground equipment. If total ground costs are to be

Table 4-5. Acceptance Test Locations

Category	At Supplier's Facility	At Prime Contractor Facility	At Government Facility	Use of Private Sector Facility
I		1	2	2
II	1	1		2*
III	1	3		2*
IV	1	3		2*
V	1	3		2*
VI	1			2*
VII	1			2*

*When capability is not available in supplier facilities

1 = first choice
2 = second choice
3 = third choice

Evaluation Criteria:

Availability of: Test equipment
Personnel skills
Interfacing equipment
Proper test facility

Minimize: Testing time
Rework time

reduced, not only must the original cost of the hardware be minimized but the operational costs as well. Hardware costs may be reduced by establishing common GSE use between programs and sharing the GSE between different test phases within the same program. Operational costs may be reduced by reducing the number of test personnel involved and simplifying the maintenance operations; this implies software flexibility rather than hardware modifications.

In conjunction with reducing operating costs, the reduction in test preparation time and test operations time will contribute greatly. This approach implies that acceptance testing must emphasize evaluating data that are operationally significant. A rapidly changing trend is an example

Table 4-6. GSE Approach

Method		Cagegory						
		I	II	III	IV	V	VI	VII
A	B	Selected Method						
Use special-purpose GSE	Use general GSE	B	B	A, B	A, B	A	A	A
Distributed GSE	Centralized GSE	B	B	B	B	A	A	A
Facility-oriented	Caravan GSE	B	B	B	B	A	A	A
Facility interface verification with simulators	Use flight article and analysis	B	-	-	-	-	-	-
Local/manual control	Remote/automated control	B	B	A, B	A, B	A	A	A
Test IFRU's after installation	Subsystem test	B	B	B	B	B	B	B
GSE for logistics IFRU test	Mission support vehicle	-	B	B	B	B	B	B
Formal qualification testing	Utilize acceptance testing and selecting qualification testing	B	B	B	B	B	B	B
Prime selection criteria: Minimize costs Share GSE Use OBCO as much as possible								

of operationally significant data. All these considerations imploy the development and use of universal test equipment that would be adaptable to most kinds of tests, including acceptance testing, on different programs, principally by software changes. Some ground support equipment will be required in addition to the universal test equipment.

If the universal test equipment is built in a modular fashion, separate modules may be utilized for acceptance testing Category II, III, IV, and V-type hardware. This implies that separate modules of the universal test equipment will be used at the supplier's facility for acceptance testing.

Category VI and VII equipment may be acceptance-tested utilizing only ground support equipment or by adapting existing equipment.

Initial Flight Hardware

Category II hardware will be primarily acceptance-tested at the supplier facility; some elements, including software, will be acceptance-tested at the prime contractor's facility.

Category III hardware is best acceptance-tested at the supplier's facility because the test equipment will be normally available there. Nothing can be gained by shipping the test equipment to the prime contractor's test facility to perform acceptance testing. If it is not possible to acceptance-test at the supplier facility or at a private facility, the prime contractor facility may be utilized.

Category IV, V, VI, and VII hardware is best acceptance-tested at the supplier's facility. The supplier will have available assembly test sets and other test equipment to demonstrate the quality and performance of his equipment. Some of these same test sets may be utilized in acceptance testing. If it is not possible to acceptance-test at the supplier facility, or at a private facility, the prime contractor facility may be utilized.

Special-purpose equipment is normally associated with testing a partiular assembly or is oriented toward one program only. Some special-purpose equipment is jnavoidable, but where possible, general-purpose equipment will be utilized.

Resupply Flight Hardware

The in-flight replaceable units (IFRU's) supplied by vendors will be acceptance-tested at the vendor facility. After this acceptance test, the IRFU's need not be tested again except as part of a subsystem. If the IFRU is intended to be supplied to the modular space station via the orbiter, its response as part of a subsystem will first be demonstrated on the mission support vehicle.

4.6.6 FLIGHT MODULE ACCEPTANCE

Cost Considerations

One method of implementing MSS Program cost-avoidance principles is to increase usage of the GSE between test phases. The use of facility-oriented GSE will be avoided. Where possible, the GSE will be caravanned and thus must be designed to meet the highest requirements of the intended usage.

The use of caravan GSE imposes a restriction that the operational readiness status of a facility must be demonstrated without necessarily using available GSE. The interface compatibility between the GSE and the facility can be demonstrated analytically. Likewise, the interface between the module and the facility need not be demonstrated with a simulator. Interface parameters will be determined before arrival of the MSS elements. These interfaces will be verified before any connection is made.

One expensive operational item is a requirement for operators at many locations to operate distributed GSE. With centralized GSE, one operator can perform several functions. Therefore, centralized GSE will be utilized when possible. Remote and automated control will be employed and the acceptance site will have a centralized control room with centralized distribution of utilities.

Initial Flight Hardware

Some modular space station goals in relation to flight module acceptance testing are (1) maximum use of the onboard checkout function, (2) minimum costs, (3) early identification of requirements, and (4) use of common GSE between programs. In order to realize these goals, acceptance testing of Category I hardware should be performed at the prime contractor's facility. At this location, MSS expertise will be available; all other parts and subassemblies will flow to the prime contractor facility and be sequentially integrated into the total modular space station effort.

Resupply Flight Hardware

Modules that have been returned to earth by the orbiter for refurbishment or major reconfiguration will undergo re-acceptance by being mated with the mission support vehicle and having module performance verified. Because trade studies have indicated that a module returned to earth for refurbishment or major reconfiguration is not cost-effective, this acceptance flow sequence is not expected to occur very often in the planned life of the modular space station.

4.6.7 DELIVERY OF TEST AND FLIGHT MODULES

Transportation of the flight modules from the acceptance site to the launch site will be by means of Guppy-type aircraft. The advantage to this, compared to surface transportation, is that highway utility modifications are minimized and the hazards of public traffic and climatic conditions are avoided. Also, long time delays are avoided as would be the case with ocean-going barge transportation. Use of government-based air transportation, supplemented where necessary with commercial transportation services, has been very effective on past programs. Some of the vehicles delivered by this method have been larger and heavier than the MSS Program elements. So, with minor modifications, this method can be utilized most effectively to deliver test and flight modules to the next using site.

To accomplish land transportation from the acceptance site to the nearest large commercial or military airfield, the highway transporter will be used. Because this device is basically a four-wheeled transporter, it need not be attached to a tractor or truck for non-moving stability. The wheels can be locked in the non-moving mode. This design will allow the highway transporter to be loaded directly aboard the Guppy aircraft for tiedown to the aircraft structure. The transporter, originally assigned to a particular flight module at the manufacturing site, is expected to caravan with the module until the module is launched into orbit. At that time, the transporter will be returned to the manufacturing site for next assignment. A highway transporter assigned to a test module is expected to caravan with that module until it is no longer needed. At that time, it will be returned to the manufacturing site for further assignment.

Using the Apollo air transportation rationale (that leakage is negligible and therefore a negative pressure differential is not possible, even if the aircraft should make a fast letdown) a pressurization capability will not be provided aboard the highway transporter.

Figure 4-11 is an artist's conception of the highway transporter. This concept permits the vertical support arms to be movable so that they can be adjusted to accommodate the three different diameters of the three unique modules (core, power, station).

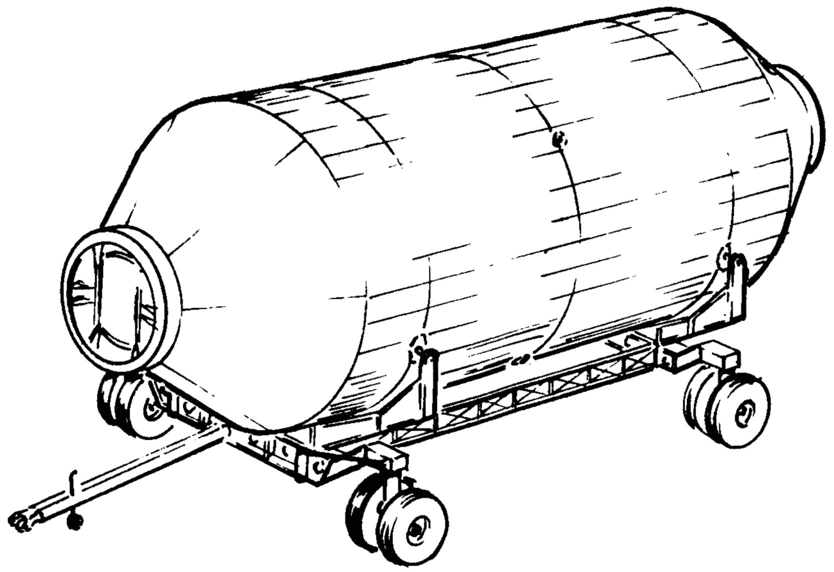


Figure 4-11. Artist's Concept of Module Transporter

4.7 LAUNCH SITE

4.7.1 RECEIVING INSPECTION

All modules transported to the launch site (via the Guppy aircraft) will undergo receiving inspection at the MSOB. This will first consist of a visual inspection of the entire module with special attention given to the interface details.

Then, an electrical interface verification test will establish gross status of the module. Included will be such standard tests as continuity, resistance, and polarity. The physical mating with the berthing port interface checkout stand will satisfy the mechanical docking interface requirements.

A second mechanical docking interface test with an orbiter docking simulator will be performed. This test will verify the interface with the orbiter in terms of disconnect commands, instrumentation, and electrical power.

4.7.2 FLIGHT MODULE ACCEPTANCE

Because the first four flight modules (for the initial station) will be acceptance-tested at the acceptance site, no additional acceptance testing is envisioned at the Launch Site. When the flight module checkout vehicle is disassembled at the prime contractor's facility and re-assembled at the launch site, it is designated the mission support vehicle, and acceptance testing of the remaining flight modules can take place.

The rationale for this sequence lies in the basic concept of acceptance testing: the CAV will be reconfigured with flight-type subsystems; when it again becomes operational as the flight module checkout vehicle, a CAV module will be removed and a flight module substituted for acceptance. The flight module checkout vehicle modules will then be transferred to the launch site and become the mission support vehicle.

For the acceptance test, the flight module will be docked to the mission support vehicle. All interface connections will be made and the module powered up per the operating procedures. Prime control mode will be by the onboard checkout capability with UTE in a monitoring mode.

4.7.3 PRELAUNCH AND LAUNCH

Prelaunch operations start by a complete servicing of functions and requirements which are not time-critical. As an example, the radiators must be filled with Freon and sealed. Potable water storage components and plumbing must be sterilized and filled with pretested sterile water. Food and all preparation and serving utensils are stowed. All recreation equipment, isotonic equipment, and medical and dental equipment must be stowed. Because a full complement of supplies will not be aboard at initial launch, a manifest will be required to control all items stowed.

Immediately after servicing the nontime-critical items, a weight and balance determination will be made. This will be required primarily for the shuttle c.g. control and also will be used for guidance and control calculations necessary for an orbiting space station. As time-critical items are added at the launch pad, the weight and balance determination will be updated by calculation. The module will be purged with clean dry air and then secured for flight.

Next, the module will be loaded into the orbiter cargo bay, docked interface verification established, and support and tiedown points verified.

At the launch pad, ground control will be established. Although the modules are launched in an inert condition, safety demands that any pressurized components or assemblies be monitored at the orbiter cockpit as well as the Launch Control Center. Time-critical items will be stored (as applicable) and clean dry air supplied to the module interior if the hatch is opened for access. After launch, no continuous pressurization equipment will be active until initiated by a crewman boarding the module in earth orbit.

4.7.4 MAINTENANCE AND REFURBISHMENT

When the module is returned to the launch site (by means of the orbiter) for refurbishment, the module will be unloaded at the modified VAB, loaded aboard the highway transporter, and delivered to the MSOB. Servicing will then consist of draining, purging, and sterilizing the potable water components and tubing, venting and purging all oxygen and hydrogen storage components and tubes, prior to starting any maintenance and refurbishment activity.

Major modifications to basic structure, subsystem assemblies and interfaces, may require recycling the modules through a modified acceptance procedure. If this should occur during the initial buildup period, the returned module would be recycled through the manufacturing and acceptance sites. After the initial station becomes operational, returned modules will undergo any major modification and re-acceptance at the launch site, utilizing the mission support vehicle for re-acceptance testing.

5. FACILITIES

5.1 PURPOSE

This section specifies the facilities requirements for premission operations of the modular space station (MSS). Special facility requirements for launch operations are presented in Section 8 of this document. Requirements for the other modular station mission facilities are not significantly different from those identified for the 33-foot diameter solar powered station. Space Station Program Phase C/D Facility Utilization Plan, SD 70-139, presents other mission operations facilities identified for the 33-foot diameter station.

In addition to the facilities requirements, an analysis of potentially usuable Government-owned and operated facilities and a gross analysis of the applicable industrial base facilities were conducted.

5.2 SCOPE

Facilities requirements have been studied and established at the site level and are treated separately as Government-base facilities and industrial-base facilities. Government-base facilities are defined as those totally owned and operated by the Government; industrial-base facilities are those owned by either the Government or a contractor, but managed and operated solely by a contractor. Typical considerations in site definition are environment, floor area, power and services, specialized handling capability, location, and suitability for joint usage.

Studies were conducted to identify the facility requirements of the major program operational flows (Figure 5-1) with reference to the program master phasing chart and the program elements requiring facility system use. Known major and unique facilities and equipment requirements are identified and existing facilities which may be used either as is or modified are identified.

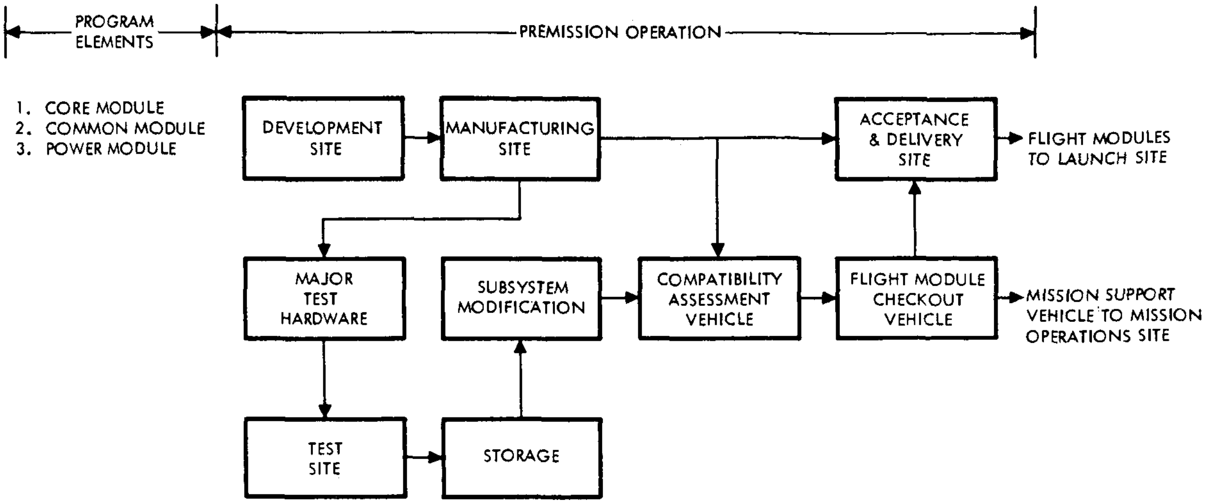


Figure 5-1. Functional Flow Chart

5.3 REQUIREMENTS SUMMARY

The facilities concept and approach is to make maximum use of existing facility systems in both the Government and industrial bases with application of cost avoidance principles. Facility modification requirements, schedule constraints, procurement and construction lead time, and transportation and handling requirements are measured against this baseline for final selection. Table 5-1 summarizes the major premission operations facility system requirements. As can be seen in this table, no new or major modifications are necessary to satisfy the requirements of the MSS premission effort. The existing facilities established for the Apollo and Saturn Programs may be used as is, or with only minor modifications. The information displayed in the tabular columns is as follows:

Site - The functional sites and the major functions performed at each site.

Location - The location of the site in either the Government base or industrial base.

Purpose - The general functional purpose of the site.

Environment.- The entries indicate trade-accepted terms for defining the general type of environment required for the facility system.

Special Power and Services - The requirement for special power and services beyond normal aerospace-type facility sites. Omissions indicate that normal availability to the site is sufficient for the listed functional requirement.

Special Handling - The requirement for large or unique handling devices and equipment due to size or weight of program hardware.

Joint Use - The required site or functional operation facility systems that can be utilized on a noninterference joint basis and not requiring dedication of usage for the MSS program.

Remarks - Comments considered pertinent to the facility requirements of the site.

Facility utilization of the contractor-managed industrial-base gross projected floor space requirements is presented in Table 5-2. The

Table 5-1. Projected Facility Requirements - Phase C/D

Site	Location (Base)	Purpose	Environment	Special Power Service	Special Handling	Joint Use	Remarks
Development							
Development laboratories	Industrial	Laboratory tests	Typical laboratory			Yes	Utilize existing general laboratories facilities and capabilities available within the industrial complex
	Industrial	Structural static test	Weather protection		Yes	Yes	Utilize existing facility at Downey, Calif.
	Industrial or Government	Acoustic	Typical large article laboratory		Yes	Yes	Utilize existing Chambers at Wyle Laboratory, Huntsville, Ala., or MSC, Houston, Texas
	Industrial	Dynamic structural test	Weather protection		Yes	Yes	Utilize Space Systems Development Facility at at Downey, Calif.
	Industrial	Compatibility assessment vehicle	Controlled	Yes	Yes	Yes	Utilize existing VAB at Seal Beach, Calif.
Manufacturing							
Fabrication components	Industrial	Forming, bonding, and processing	Typical manufacture				
		Bulkhead forming			Yes	Yes	Stretch forming
		Floor and stringer bonding	Controlled		Yes	Yes	Utilize existing Seal Beach, Calif. autoclave
		Processing	Controlled		Yes	Yes	
Structural assembly	Industrial	Assembly-weld structure	Controlled		Yes	Yes	Utilize existing Seal Beach, Calif. welding facilities
	Industrial	Verify structure	Isolation		Yes	Yes	Utilize existing Seal Beach, Calif. pneumo-static test site
	Industrial	Install sub-system into structure	Controlled	GSE	Yes	Yes	Utilize existing Downey, Calif. Bldg 290 facilities
Acceptance Delivery	Industrial	Acceptance test	Controlled	GSE	Yes	No	Utilize existing VAB at Seal Beach, Calif.
	Government	Transportation to launch/test sites		GSE	Yes	Yes	Utilize existing Guppy systems

Table 5-2. Phase C/D Projected Floor Space Requirements (Initial Station)

Facilities (MSS)	1975	1976	1977	1978	1979	1980	1981
Office	75,000	709,000	1,320,000	1,455,000	1,067,000	438,000	72,000
Manufacturing	5,000	65,000	162,000	727,000	600,000	271,000	21,000
Laboratory	6,000	103,000	305,000	515,000	311,000	96,000	5,000
Administrative services	6,000	56,000	244,000	334,000	244,000	70,000	140,000
Total	92,000	933,000	2,031,000	3,031,000	2,222,000	875,000	238,000

industrial-base gross projected floor space requirements for the sites are developed by utilizing the contractor's industrial engineering data and experience gained during the Apollo and Saturn Programs. These data and experience, when applied to program hardware schedules, facility lead times, headcount quantity and buildup, plus development and manufacturing requirements and sequences, yielded gross floor area requirements. These floor area requirements were then compared to the contractor's previous program floor area requirements and adjusted where necessary to reflect realistic annual sales versus floor area factors.

These projected requirements do not imply that the Phase D prime contractor must have operational management of an industrial-base site of the size displayed in the tables. Major decisions of make or buy, availabilities of other prime contractor corporate facilities, and subsequent plans of Government-furnished equipment significantly affect total contractor-dependent floor space requirements.

The following sections describing the technical facility site analysis lists estimated floor space requirements, where known. However, precise projected floor space requires studies during subsequent phases of the program.

5.4 DEVELOPMENT SITE

Because of dynamic interfaces between the development laboratories and test and production operations, the facility system requirements for Phases C/D are established in the prime-contractor industrial-base center, except where certain unique requirements for major test facilities exist in the Government base. Use of the existing Government-leased air transportation system developed in support of the Apollo Program and the S-IVB booster permits use of the cost-avoidance concept. The facility requirements are defined by major functional area gross requirements (Figure 5-2).

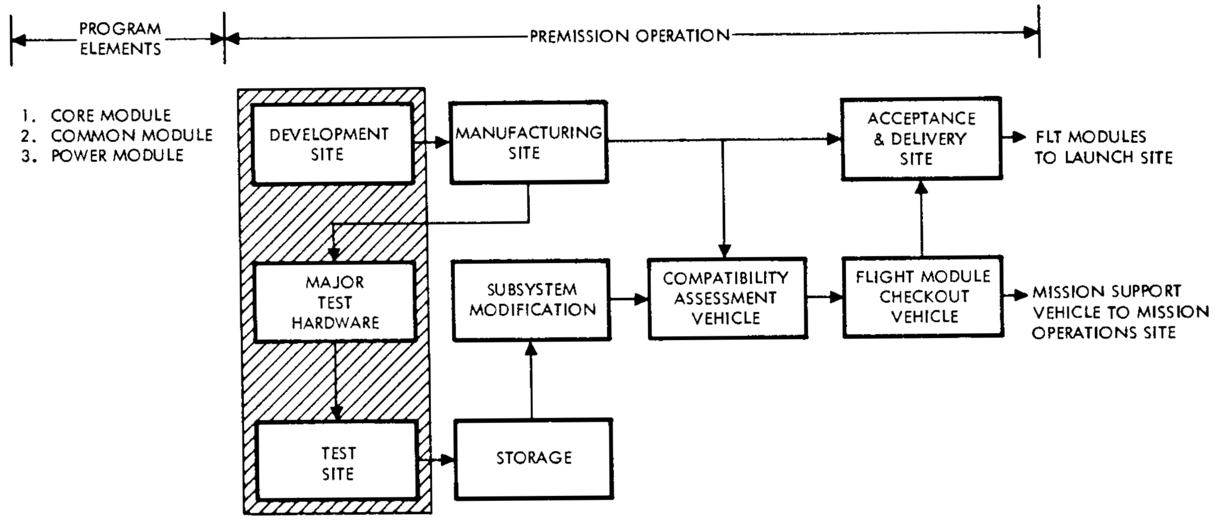


Figure 5-2. Functional Flow Chart Showing Development Site Interfaces

5.4.1 DEVELOPMENT TEST LABORATORIES

Facilities requirements for MSS development testing have been identified by correlation of Section 2 of this document and program test philosophy. Significant development test facility requirements are as follows:

1. Testing is to be performed at the highest assembly level practical.

2. Development and acceptance testing is to be accomplished in accordance with an integrated program and the MSS program element specifications.

3. The major test articles require highly complex multidiscipline facilities for structural, acoustic, and dynamic testing. The 14' 8'' diameter articles, completely assembled and ready for test, range in height from 38 feet to 40 feet.

Laboratory area requirements for Phases C and D are given in Table 5-2, and planned testing start dates for the major test articles are given in Section 2, Figure 2-2. Phase C test facilities are used for feasibility and breadboard development testing. Laboratory facilities existing within the industrial base are considered adequate to meet these program needs, and their use will complement the stated cost avoidance and reduction principle. Approximately 24,000 square feet of development test laboratory area is required for work in disciplines such as chemical analysis, chemical processing, metallurgy, metallographics, welding development, plastics development and processing, and spectrophotometry.

Services and equipment for support of these disciplines are primarily standard items that are currently available within existing laboratories: electrical power; natural and special gases; domestic and distilled, deionized water, etc. Certain areas require conventional temperature control, high-intensity lighting, and contamination control.

During Phase D, the feasibility and development testing begun in Phase C is expanded to include components, subassemblies, and subsystems. Phase D laboratory requirements, therefore, are considerably more complex. Heavier equipment is required to handle the large test items; hazardous operations involving large systems must be conducted in isolated locations; and multidiscipline laboratories are needed to test the combined subsystems. Again, existing Government-base and industrial-base facilities are, with minor modifications and upgrading, considered adequate for performance of all known testing at this level. Selection rationale is based on cost avoidance of construction and operations costs of new test facilities.

Pneumatic Test Laboratory

A pneumatic test laboratory is required for pneumatic testing of subsystems with regulated pressures up to approximately 5000 psi at flows to 6 pounds per second. This laboratory requires test cells approximately 40 feet in all dimensions adjoining an approximately 800-square-foot concrete control center. The control center requires pneumatic monitoring and control, data acquisition, and data-reduction equipment. Storage and recovery systems for helium gas are also required.

Environmental and Space Simulation Laboratory

The environmental and space simulation laboratory is required for environmental testing for components, subsystems, and systems. Chambers, boxes, and rooms designed to provide oxygen, humidity, salt spray, altitude, and temperature (hot and cold) environments are needed. Certain areas require contamination control. Large chambers require fixed or portable handling devices such as monorail cranes and A-frame hoists for specimen loading.

Neutral-Buoyancy Test Laboratory

The neutral-buoyance test laboratory provides zero-g simulation for development testing of the docking subsystem, cargo-handling, crew restraints, hand holds, etc. The major item of this laboratory is the pool and associated water conditioning equipment in which the test specimens are suspended. A series of view ports in the side of the pool or a submerged viewing caisson are required for visual monitoring and photography of test subjects. An approximately 1500-square-foot control center and change room is required adjacent to the pool for test specimen buildup, instrumentation installation, breathing equipment repair, swimmer change, and data acquisition. An overhead fixed or portable crane of approximately 10-ton capacity is required for placement and removal of test fixtures and specimens.

Structural Test Laboratory

A structural test laboratory is required for feasibility and development testing of subassemblies and components of the MSS. Special flooring is required for holding static structural articles in position while test loads are applied. An area is required for data acquisition and control of vibration, shock, and acceleration equipment. Isolation masses must be installed in the shaker areas to prevent transmission of vibration to adjacent areas. A fixed or portable overhead crane system of approximately 20-ton capacity is needed for loading specimens.

Acoustical Test Laboratory

The acoustical test laboratory is used for feasibility and development structural testing of subsystem assemblies and components through the use of high-pressure sound waves. Facilities include a chamber approximately 20 feet by 20 feet by 25 feet high in which sound levels up to 160 decibles are produced, an approximately 1500-square-foot control center to house the acoustic chamber controls, instrumentation for monitoring sound levels, and automatic data acquisition equipment

5.4.2 DEVELOPMENT TEST ARTICLES

Major test articles that affect facility requirements are indicated in Table 5-3.

Structural Static Test Articles

A structural static test facility will be required to support structural testing. The test articles will have a maximum diameter of 15 feet by 40 feet in height and may be positioned vertically or horizontal for testing purposes. Full access to the test article with an overhead crane of 10-ton capacity is required. Approximately 3000 square feet is needed for a control center close to the test area to house the electronic data collection systems. Existing Apollo facilities are available with only minor modifications required.

Acoustical Test Article

The acoustical test article requires an acoustical reverberation chamber capable of housing a 15-foot-diameter by 40-foot-high test vehicle. Vibro-acoustic simulation of sound pressure levels at launch is required.

The size of the test article limits the reverberation chamber that can be considered in both Government and industrial bases to those having minimum dimensions of 15 by 15 by 40 feet. One known chamber that meets the size requirements is the facility at the Manned Spacecraft Center, Houston, Texas. The 15-foot-diameter by 40-foot-high test article can be transported horizontally to this facility using the Guppy aircraft.

Dynamic Structural Test Modules

Dynamic structural test facilities are required to accommodate individually a full size space station core module structure, a full size common module structure, and a full size power boom module structure with dummy-type subsystems installed. Isolation and reaction masses are required to assure proper dynamic input to the test module. An overhead crane with a capacity of 15 tons will be required to position the test modules.

Facility systems for dynamic testing of the modules exist within both the industrial and Government bases. MSFC facilities exist for both horizontal and vertical positioning of the test modules. Program schedules also allow the existing NASA Apollo space systems development facility at Downey, Calif. to be utilized for the dynamic structural test program.

Table 5-3. Major Test Article Test Requirements

Major Test Articles	Scale	Systems Operational Testing	Test Environment
Structural test			
1. Core module	Full size	Flight-type primary and secondary structure with berthing assemblies installed	Ambient
2. Power boom	Full size	Same	Ambient
3. Common module	Full size	Same	Ambient
Acoustical test			
1. Core module	Full size	Dummy systems and flight-type structure	Acoustic
2. Power boom	Full size	Same	Acoustic
4. Common module	Full size	Same	Acoustic
Dynamic test			
1. Core module	Full size	Dummy systems and flight-type structure	Vibration
2. Power boom	Full size	Same	Vibration
3. Common module	Full size	Same	Vibration
Compatibility assessment vehicle	Full size	Flight-type structure systems 1. Core module (1) 2. Power boom (1) 3. Station module(3)	Controlled
Mission support and checkout vehicle	Full size	Flight-type structure systems 1. Core module (2) 2. Power boom (1) 3. Station module(3)	Controlled

Compatibility Assessment Vehicle

The compatibility assessment vehicle is used as a prototype subsystem integration tool and, as such, requires a full-size core module, power module, and common modules in an attached configuration (Figure 5-3). The attached configuration will require an area approximately 150 feet wide, 100 feet long, and 100 feet high, with a 20-ton overhead crane. This multistory-type building will contain adjacent floor area for equipment, office, and bench-type support areas. Primary and secondary electrical power distribution, environmental control of vehicle interior, fluid and gas services, and cooling water loops are required. Certain material handling devices and elevator access is required for systems installation removal.

To maximize the benefits of this integration tool with the flight article design, this facility should be at the prime contractor's location. The existing Saturn S-II vertical assembly facility at Seal Beach, Calif. will fulfill all known requirements for housing this vehicle with only the minor modifications shown in Figure 5-3.

Flight Module Checkout Vehicle

The flight module checkout vehicle is used as a flight system integration tool. It is the next generation of core module, power boom module, and common modules containing flight hardware. This vehicle replaces the compatibility assessment vehicle and will utilize the same facilities.

5.4.3 COMPUTER DEVELOPMENT FACILITY

A computer development facility is required for performing engineering development and evaluation testing (D&ET) of the station operational computer program. This facility will require a general-purpose computing system including a general-purpose computer, a magnetic tape controller, magnetic tape drives, a paper tape punch and reader, typewriters, a card reader, and a line printer. This facility will also house an ISS central processor substation as shown in Figure 5-4. The required general-purpose computer facilities exist within the industrial base complex and will require only minor update to support the modular space station D&ET.

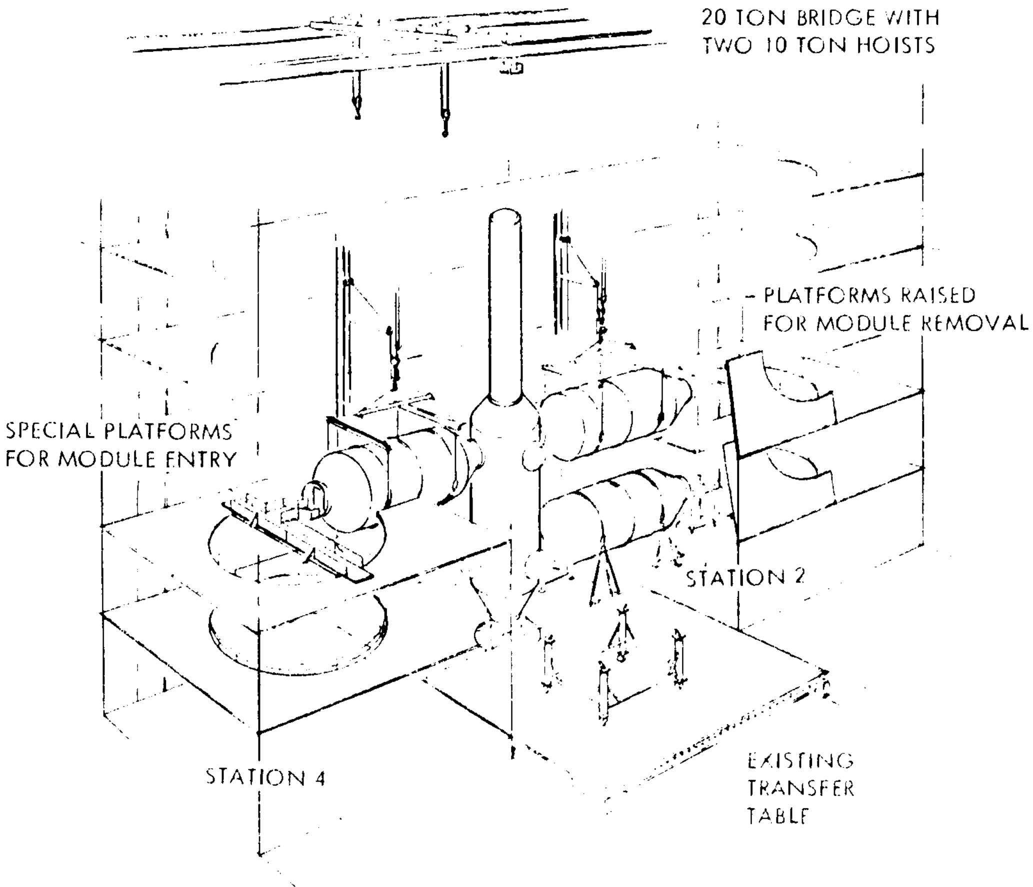


Figure 5-3. Compatibility Assessment Vehicle Concept

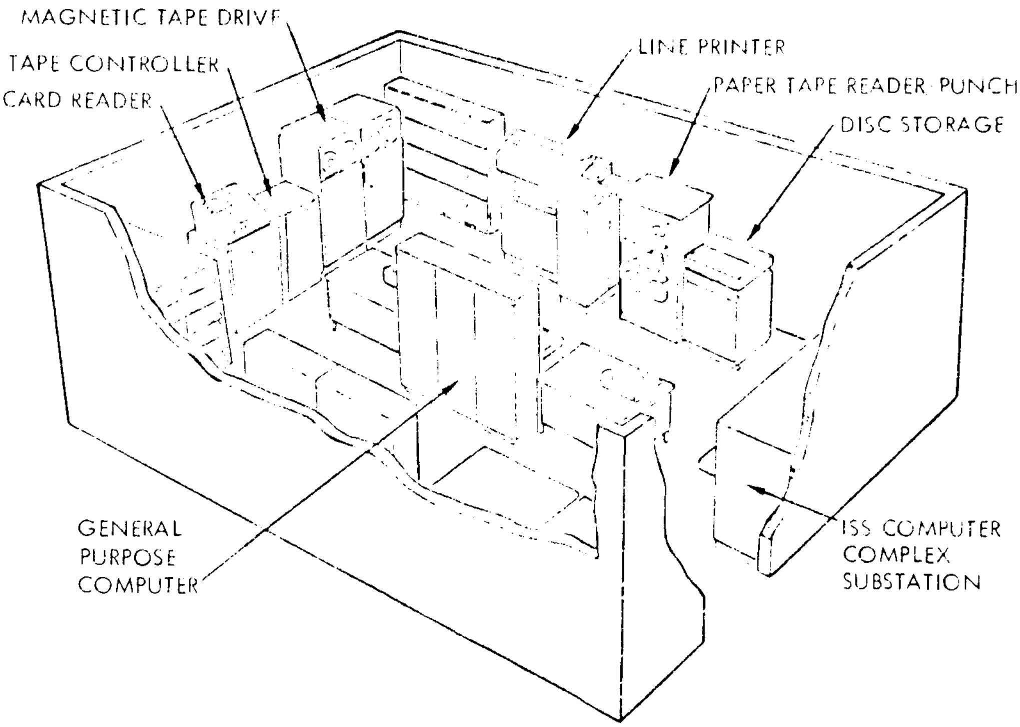


Figure 5-4. Development and Evaluation Test Facility

5.5 MANUFACTURING SITE

This section, which is correlated with Section 3 of this document, describes the significant facility requirements for fabrication, assembly installation, verification testing, handling, and quality control of the MSS program elements (core module, station module, and power module) (Figure 5-5).

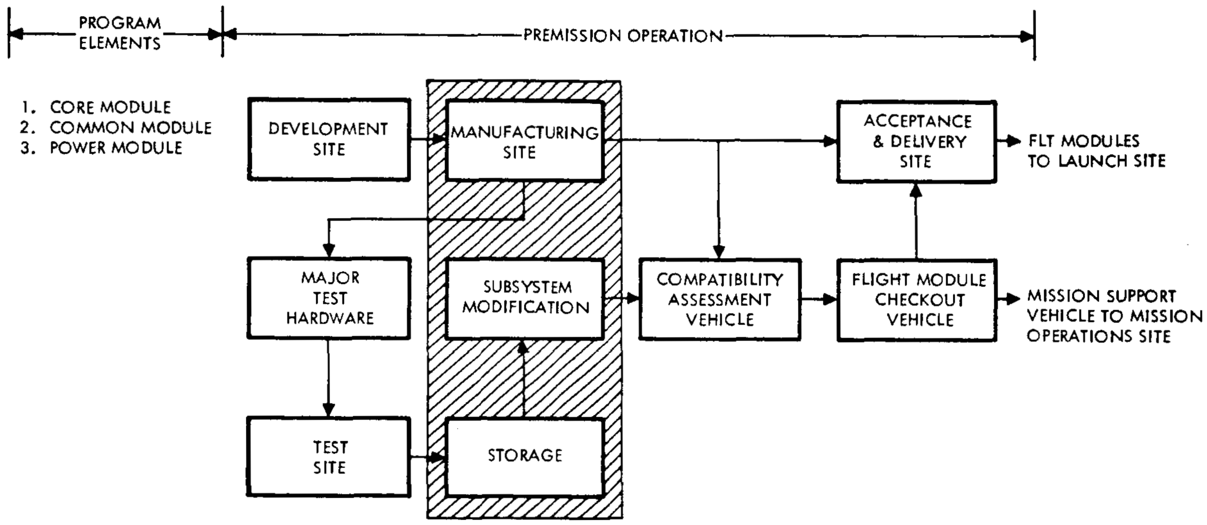


Figure 5-5. Functional Flow Chart Showing Manufacturing Site Interfaces

Significant program factors that influence the facility systems requirements are:

1. Hardware quantity and schedule
2. Program element, weight, height, length, and diameter
3. Pressure and leak checking of modules

4. Application of flight environments during component and subassembly acceptance and verification testing

5. Use of bonded honeycomb sandwich construction for the core module pressure bulkheads and the longitudinal floors of the station module.

Major facility systems established for other space programs, applicable to Phases C and D of the MSS program, exist in the Government-owned, contractor-operated industrial base centers at Seal Beach and Downey, Calif.

These industrial base facilities have no known restrictions that would prohibit their use on a joint basis with compatible programs. They are located in major industrial areas where nearby commercially owned facilities may be used to supplement present facility capability and eliminate the need for major modification or expansion of existing facilities.

For maximum application of the cost-avoidance and reduction principle, existing facilities of the S-II and Apollo programs are available. They are capable of meeting dimensional, quantity, and schedule requirements of flight station and major test articles. Significant requirements of the manufacturing site for the modular space station elements are the high-bay assembly areas. Each of the recommended facility centers has adequate high-bay and low-bay area and handling systems. The existing facilities systems require only minor modification for fabrication, assembly, and checkout of the MSS elements.

Significant component, subsystem, and system development test and verification facility systems, remaining from the Saturn launch vehicle and Apollo command and service module programs, are supplemented with major facilities at various NASA centers. Combining both the manufacturing and acceptance and delivery site into the two mentioned industrial bases will provide the following facility advantages:

1. Cost avoidance of new construction or major modification of other facility bases

2. A 50 percent cost reduction of low-bay assembly areas (existing installation and assembly stations with minor adaptations can be used for subsystem installation and integrated checkout)

3. Availability of the compatibility assessment vehicle for reference during subsystem installation and verification.

5.5.1 MOCKUPS

Mockups of the core and station modules fabricated during Phase B require continuation of present facility provisioning through Phases C and D. An area of approximately 15,000 square feet is required to house and service the mockups. Utilities, primary and secondary power distribution systems, fire protection systems, and an overhead crane of approximately 10-ton capacity are required. Walls or draperies with panels are needed for display of diagrams, small components, and subsystem mockups. An adjacent conference room accommodating up to 20 people is required. Shops suitable for these activities are currently available and require no modification for use in Phases C and D.

5.5.2 PHASE C/D PROJECTIONS

Significant factors influencing manufacturing facility requirements are the need for formed skin sections 11 feet wide and 27 feet 3 inches long with bonded ring stiffness; upper and lower six panel, segmented, compound-contoured bulkheads; honeycomb sandwich longitudinal flat floors; and 12-foot diameter by 10-inch thick honeycomb sandwich pressure bulkheads in the core module. A stretch-forming facility is required to fabricate the light-weight compound-contour bulkhead panels for the core module and the station modules.

Facility systems exist in the industrial base and there are no known impacts for co-usage of the facilities nor known major modifications required for the MSS program utilization.

The bulkhead assembly requires facilities for welding the panel sections into a completed bulkhead assembly prior to delivery to the assembly facility. Environmental control, high-level lighting, automatic welding equipment, and overhead handling cranes of 10-ton capacity are required. The existing S-II welding facilities at Seal Beach can be used on the modular space station bulkhead.

The most significant facility system is that required for subassembly, assembly, subsystem installation, verification testing, and handling of the module elements as shown in the concept facility utilization flow chart (Figure 5-6).

Current program schedules require a maximum of three high-bay vertical assembly areas. Preliminary analysis indicates that a minimum of 15 and a maximum of 25 low-bay subassembly areas are required in addition to in-process storage areas. The Seal Beach and Downey industrial base centers have more than the maximum number required. Other major or unique facility requirements for the program elements are discussed in the following paragraphs.

Fabrication

Subsystems of the MSS are classified as mechanical, electrical, or structural. Below the subsystem level are the requirements for fabrication of details, components, and assemblies. Electrical and mechanical subsystems, though complex, are not expected to impose excessive demands on existing fabrication facilities. Manufacture of details, components, and assemblies is within the industrial base capability for cutting, machining, processing, bonding, and mechanical and electrical fabrication.

A bonding facility system is required for bonding of the 15-foot diameter stiffeners to the aluminum station module skins. The system consists of a process cleaning station, layup station, and autoclave bonding station. The existing S-II bonding system requires minor modifications for the conversion from 33-foot diameter hemispheric parts to 15-foot diameter 27-foot, 3-inch long quarter panel skins.

Assembly and Installation

The manufacturing baseline requirement for use of existing facilities requires both vertical and horizontal assembly steps. Significant rationale substantiating the vertical and horizontal modes of assembly are (1) gravitational assist in final alignment, (2) reduction of tooling requirements for vertical circumferential close-out welding, and (3) ease of equipment installation requires the longitudinal floors to be in the horizontal position.

The structural assembly facility system is based on "as-is" use of existing low-bay areas: 50- by 50-foot work stations 35 feet high for assembly of details and 12- to 15-foot diameter subassemblies, and overhead bridge crane systems of approximately 10-ton capacity. Environmental control and primary and secondary electrical power distribution and domestic and treated water systems are required. This facility must be geographically close to the final assembly and subsystem installation facility to reduce handling and transportation costs.

High-bay (approximately 60 feet high) facilities are required to complete the core module structural assembly. The vertical assembly work stations require overhead cranes of approximately 15-ton capacity to position subassemblies during final structural assembly. Handling devices such as transfer tables and high-capacity overhead derricks are needed for transfer of completed core modules weighing up to 25,000 pounds between stations and removal of articles from assembly tools to prepare for shipment. The low- and high-bay assembly stations require access and work platforms at proper heights (Figure 5-6) for introduction of components, subassemblies, and subsystems, and entry of personnel. Environmental control, high-level

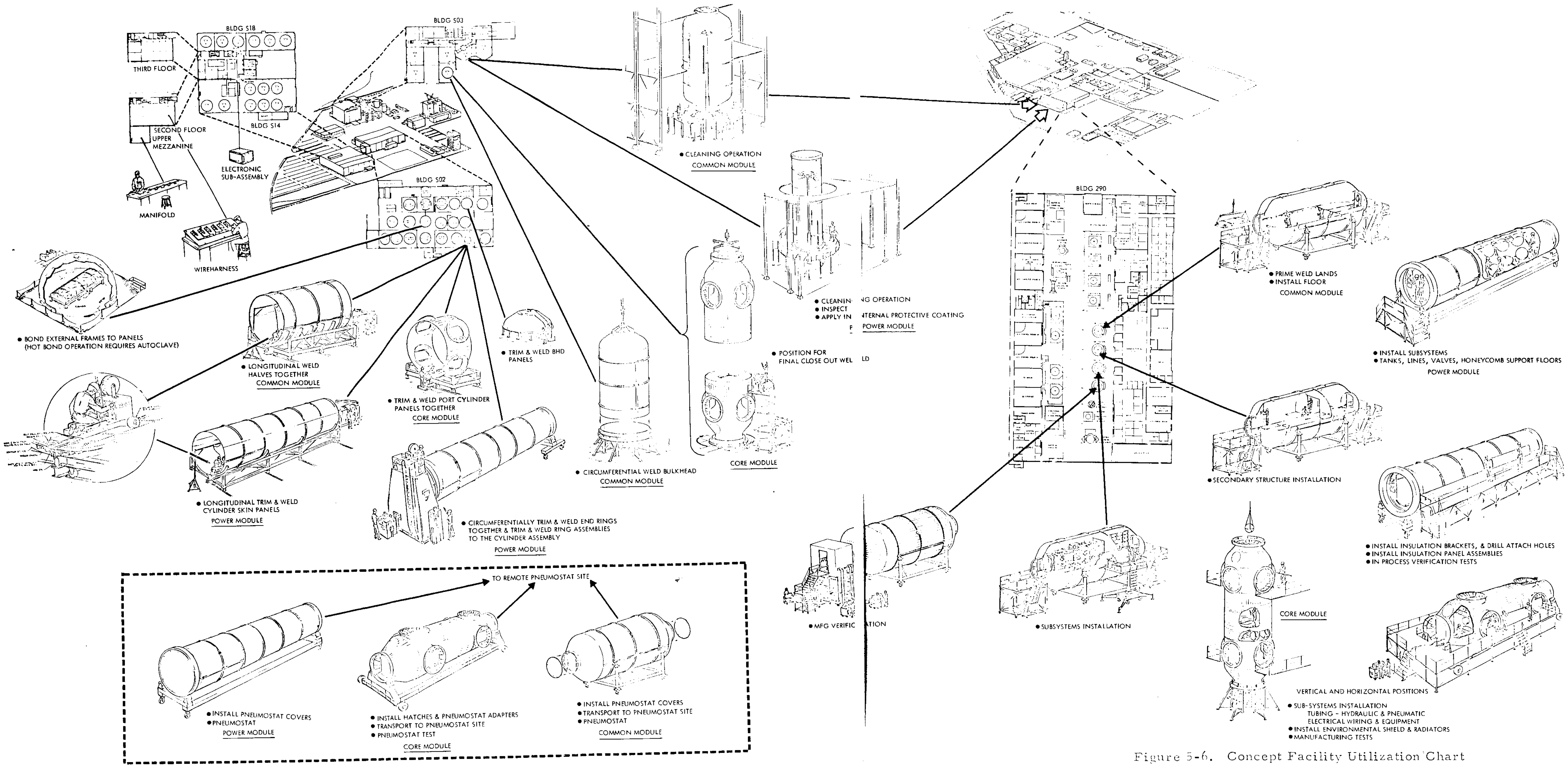


Figure 5-6. Concept Facility Utilization Chart

lighting, primary and secondary electrical power distribution systems, and fluid and gas distribution systems are needed at each station.

Manufacturing development fixtures and system mockups will be utilized to determine tubing and wire harness configurations where time phasing of ground test vehicles indicate their inability to support the fabrication and assembly schedules. Facilities for location of the development fixutres and system mockups are available within the Downey and Seal Beach industrial bases.

In-Process Testing

Facility requirements for in-process verification testing are defined by the functional breakdown of the manufacturing site though these facilities actually may be separated in location and functional area.

Facility requirements for this type of testing (the mechanical and electrical subsystems of all program elements) are not considered unique; most will be accomplished with handheld inspection aids. The performance-verification facility systems for these components and subassemblies require laboratories that can simulate flight environments while performance testing is accomplished. In general, these facilities exist within the industrial base and require only equipment upgrading to meet the needs of the MSS program.

Full structural testing is a requirement unique to man-rated space vehicles such as the modular space station. The facility systems required to perform the in-process tests of the structural subsystems include not only hand-held inspection aids, but in some cases, a separate area within the operational area to perform X-ray, dye-penetrant, and fit checks of master tools.

Weld X-ray facilities are required adjacent to the bulkhead assembly weld area and the MSS structural assembly area. Existing Seal Beach facilities can be used with equipment modifications.

Weld dye-penetrant facilities are required for surface assessment of welding before articles are sent to X-ray. These facilities must be adjacent to the automatic structural welding areas and the hand-welding areas. The existing industrial base facilities are adequate as is.

Pressure systems verification facilities are required to verify the structural integrity of pressure vessels, piping, and full MSS structures. Because of the hazards associated with pneumatic testing of unproven structures, these facilities require remote locations or extreme safety precautions such as blast-proof test cells. The existing industrial base facilities of the Apollo and Saturn programs meet the needs for pressure testing of all MSS program elements and subsystems without major expansion or modification.

Subsystems installation in-process test facilities are required for electrical continuity and pressure systems leak and flow tests. The checkout station for these functions is located in the final assembly and checkout area where work and access platforms can be available at proper levels for module entry. Environmental control, high- and low-pressure fluids and gases, and primary and secondary electrical power distribution systems are needed. Floor area adjacent to the vehicle is required for additional monitoring and test control equipment, ground support equipment, and verification testing of the power and station modules. Further studies are required to determine the exact configuration of the total floor area after the performance test procedures are established.

Quality Control Laboratories

The quality control laboratories (metrology and calibration) are required for instrument calibration and repair to assure data reliability via traceability to the National Bureau of Standards. All instruments, gauges, and measurement facilities used in the development, in-process, and acceptance checkout of MSS program elements are processed through these laboratories.

The metrology laboratory requires secondary standard for traceability to the National Bureau of Standards. The calibration laboratories supplement the metrology laboratory with repair and secondary capability. Facilities and utilities requirements consist of conventional shielded rooms; secondary power distribution systems; distilled water sources; temperature, humidity, and cleanliness control of environment; vibration isolation; and high-level lighting. Facilities systems for these functions exist without need for modification. Some equipment replacement is necessary to achieve Phase D state of the art.

Servicing and Support

Considerable servicing and support items are required for the MSS program and any large facility (site) supporting it. Basic utilities and supporting services exist at the present NASA sites and at most major aerospace contractor facilities. Primary supplies of natural gas, domestic water supplies, sewerage, electrical power, and secondary supply distribution systems require adjustments only to reach specific points or areas. On-site compressors supply sufficient secondary plant air volume and pressure and will require adjustments only to reach specific points or areas. The peculiar requirements of industrial gases, fluids, vacuum, etc., are to be determined concurrently with site and building layouts. Depending on the volumes used at specific sites, either mobile or fixed supplies of gases, fluids, and vacuum are needed.

5.6 ACCEPTANCE AND DELIVERY SITE

This section, which is correlated with Section 3 of this document, Logistics Support (Section 7), and Test (Section 2), is a description of the major facility requirements and modifications for acceptance checkout and delivery of the MSS program elements (Figure 5-7).

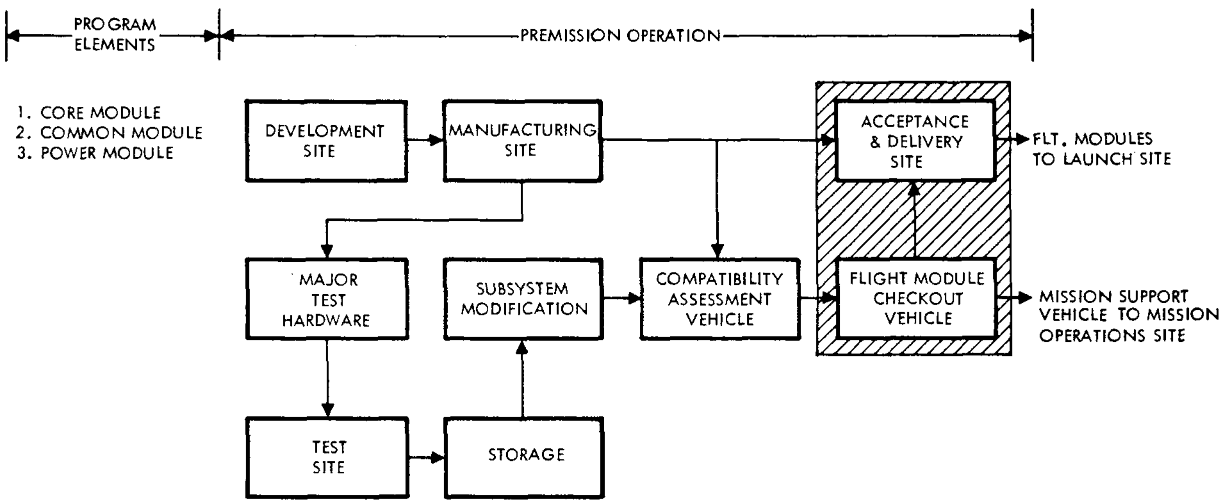


Figure 5-7. Functional Flow Chart Showing Acceptance and Delivery Site Interfaces

Established with application of cost-avoidance and reduction principles, the facilities approach defines facility systems requirements for acceptance and delivery in the industrial base, eliminates the need for intermediate acceptance test facilities, and avoids excessive transportation and handling of flight-ready hardware. Significant program factors affecting acceptance and delivery facility requirements are:

1. Shipment of the modules via special air transport

2. Use of universal test equipment (UTE) to limit the amount of GSE required

3. Acceptance testing of components and subassemblies under flight environments (vibration, temperature, and pressure).

5.6.1 ACCEPTANCE TESTING FACILITIES REQUIREMENTS

Components and Subassemblies

Acceptance testing of components and subassemblies requires testing under simulated flight environments. These environmentally controlled facilities require static and dynamic structural test systems, and high- and low-pressure pneumatics.

Facilities developed within the aerospace industrial base for past programs are adequate for the MSS acceptance testing at this level with minor equipment updating only.

Subsystems

Subsystem acceptance testing requires complex facilities to achieve combined, simulated flight environment and subsystem performance verification at subsystem interface points. The test facility systems must include environmental control, primary and secondary electrical power distribution, and high- and low-pressure fluids and gases. Specific GSE is required to make the interface connection between the subsystem under test and the facilities systems to assure proper input and output characteristics. With only minor equipment updating, existing acceptance test facilities within the aerospace industrial base are expected to be adequate for the MSS program.

Systems

Acceptance test facility requirements for the modules are the same as those for subsystems installation and subsystem verification discussed in the Manufacturing Site section. In keeping with cost-avoidance principles, the following functions can be performed on the space station at the industrial base contractor site: subsystems installation, verification, acceptance, checkout, and preparation for integrated space station checkout. Fully integrated flight vehicle checkout of the flight modules should be performed in the same geographic area; however, unique height requirements demand use of a separate facility previously made available for the compatibility assessment vehicle (Figure 5-3).

5.6.2 TRANSPORTATION AND DELIVERY FACILITIES

This section identifies the facility requirements for transportation and in-transit servicing of the MSS program elements and major test articles from the manufacturing or acceptance and delivery site to the test or launch site.

The MSS flight modules require land transportation between and from the manufacturing site and the acceptance site to the nearest large commercial or military air field, loading aboard a special Guppy aircraft for delivery to Port Canaveral, Florida, and transloading truck to transit overland to the KSC vehicle assembly building (Figure 5-8). Test articles will require delivery to final selected test sites. Candidate sites are MSFC, Wyle Laboratories, Huntsville, Alabama, and MSC, Houston, Texas.

To arrive at facility system requirements, deliverable end items are grouped into three major categories: core modules, station modules, and power modules. Factors that significantly influence the transportation and delivery facility system requirements are dimensions and weight of the flight and test modules, quantities and scheduling of program elements, and in-transit servicing requirements of the module flight articles.

Because of the unique characteristics, size, and weight of the end items (the test flight articles), primary emphasis is placed on transportation of these elements. Flight hardware and major test articles are planned for transportation in a horizontal position.

Both current and future transportation concepts have been assessed with respect to delivery between points within the United States. Specialized aircraft have been evaluated. Extensive overland transportation was rejected in view of experience with the high costs of utility modifications (wire raising, tree trimming, and highway and bridge changes) and with the hazards of public traffic and climatic conditions.

Use of the Government-leased and proven air transportation facility system, supplemented where feasible with commerial transportation services, is suitable. The effectiveness of the existing system has been demonstrated by the S-IVB and Apollo programs, which involve transportation of space-rated vehicles up to 22 feet in diameter and 65 feet in length and weighing up to 22,000 pounds (see Figures 5-9 and 5-10). With modification of certain devices, this system is capable of meeting all significant transportation demands of major MSS program elements.

Land transporters, similar to those employed on current programs, are required for the MSS program elements. It is planned that the equipment used on the Apollo and S-IVB programs will be available (with modifications) for use on the modular space station program. A new land transporter, capable of moving the core and station modules in a horizontal position, is required, as discussed in the GSE section (IV) of this document. The number of such transporters needed remains to be determined.

Protective covers are required to protect the test and flight modules during transit. These covers must provide a limited controlled environment.

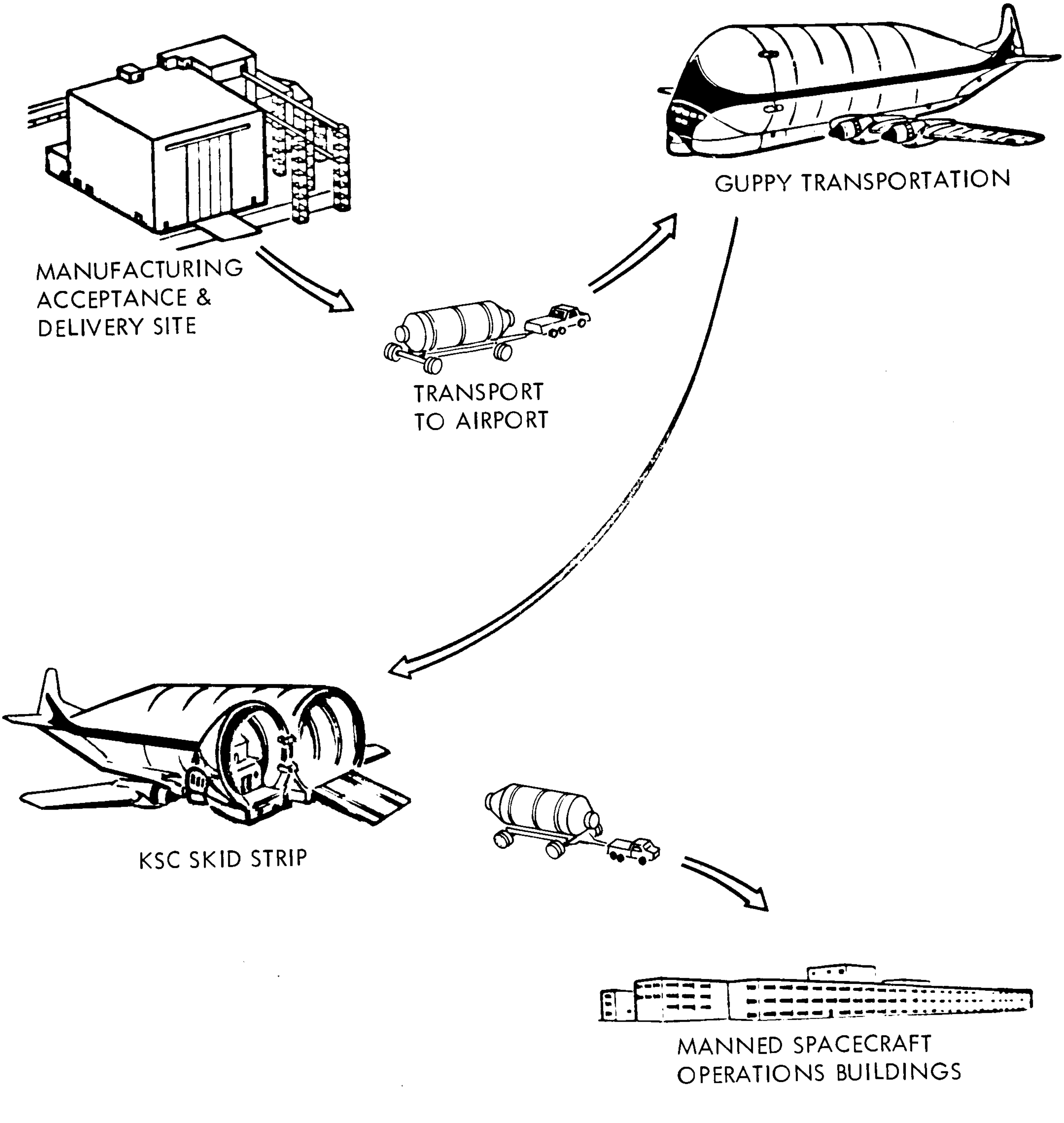
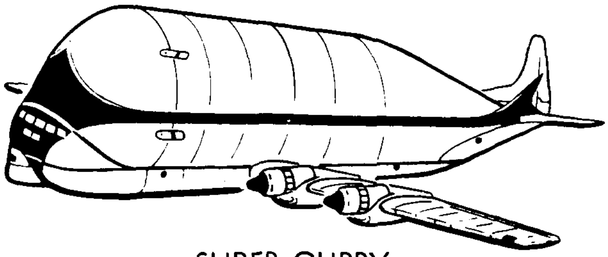


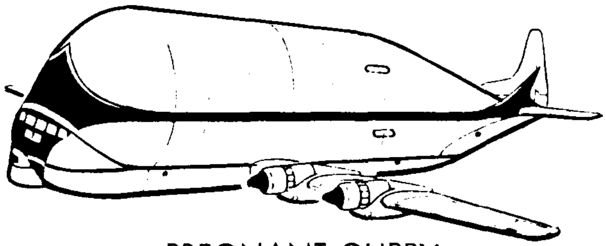
Figure 5-8. Transportation Task Flow Diagram - Space Station Module



SUPER GUPPY

RANGE	800-1200 MILES
MAXIMUM PAYLOAD CAPABILITY	45,000 POUNDS
TAKEOFF DISTANCE	8200 FT
SPEED (CRUISE)	300 MPH
CARGO SIZE	25 FT 0 IN. DIA BY 94 FT 6 IN. LONG
FUSELAGE DISPLACEMENT	49,790 CUBIC FEET
MAXIMUM GROSS WEIGHT	175,000 POUNDS
AIRCRAFT BASIC WEIGHT	104,000 POUNDS
CARGO COMPARTMENT	NOT PRESSURIZED
COCKPIT AND LOWER FORWARD COMPARTMENT	PRESSURIZED
NUMBER OF EXISTING AIRCRAFT	ONE
OWNER AND OPERATOR	AERO SPACELINES, INC.

Figure 5-9. Super Guppy



PREGNANT GUPPY

RANGE	1,000 MILES
PAYLOAD	25,000 POUNDS
TAKEOFF DISTANCE	7,000 FEET
SPEED (CRUISE)	225 MPH
CARGO SIZE	18 FT 6 IN. DIA BY APPROX 40 FT LONG
MAXIMUM GROSS WEIGHT	133,000 POUNDS
AIRCRAFT BASIC WEIGHT	89,000 POUNDS
CARGO COMPARTMENT	32,150 POUNDS
NUMBER OF EXISTING AIRCRAFT	ONE
OWNER AND OPERATOR	AERO SPACELINES, INC.

Figure 5-10. Pregnant Guppy

5.7 MANAGEMENT, DESIGN, ADMINISTRATION, AND SUPPORT SERVICES REQUIREMENTS

Management, engineering design, and administration and services require office space for program management, engineering, procurement, financial, and support personnel. Included are special areas for support activities, such as computer and data processing, cafeterias, plant protective services, and warehousing. Because of the dynamic interfaces cited previously, it is advantageous that the site be integrated with the development, manufacturing, and acceptance checkout sites at the prime contractor industrial base, consistent with Phase D decisions of make or buy, Government-furnished equipment, and use of other prime contractor corporate facilities.

On-site office area is required for program management, engineering design, and administrative services, complete with appropriate program control display rooms, NASA resident personnel provisions, training classrooms, etc. Scientific and business electronic data center computational facilities will be required to support engineering design/data analysis and management/business system applications. External communications with the mission management site will be required in areas of program flight operations support, logistics provisionings, etc.

Significant computational simulation facilities are required for supporting certain guidance and control tests identified in the Program Test section of this document. The facility system will require general-purpose analog and digital computers in addition to special-purpose equipment specific to the planned tests.

On-site receiving warehousing and shipping areas with applicable quality control inspection facilities will be required for raw, in-process, and finished materials, and for logistics storage support for program requirements. Storage areas for program GFE flight hardware will require bonded or secured on-site inventory and will require facility security provisions plus controlled environments in certain areas.

Typical site and personnel administrative services facilities are required for institutional support, such as employee first-aid, emergency medical provisions, cafeterias, fire and plant security protection, and maintenance shops.

Standard utility primary supply and secondary distribution of electrical power, water, natural gas, and sanitary sewage systems are required.

Facilities systems of this type exist within the major aerospace industrial-base centers and are available for use on the MSS program.

6. TRAINING

6.1 PURPOSE

This section provides the base for a definitive NASA training plan for NASA personnel assigned to interface with the modular space station (MSS) elements and their associated equipment. The detailed plan is developed and initially implemented in Phase C; however, major implementation occurs in the Phase D training program. This section is a preliminary plan from which NASA and others may obtain the visibility required to conduct the Phase C (design) and Phase D (development and operations) planning and training for the MSS program. The Phase C contractor's plan will provide a centralized source of material from which NASA management, training planners, coordinators, crew members, and support personnel can plan for real-time activities as they relate to the MSS contractor training program.

6.2 MSS TRAINING SCOPE

This section defines the training required for NASA station crews and mission management, support, and administrative personnel for the modular space station. It includes requirements for training planning, training, and training interfaces for NASA personnel, as well as crew manning rationale and gross training time phasing with emphasis on station crews.

Unique training equipment requirements for the station crew are identified, and gross training course outlines, course descriptions, and training documentation approach and format are defined. Contractor requirements for accomplishing support tasks are described.

The training system, which should be implemented by the Phase C contractor, consists of four levels of training: orientation, familiarization, mechanization, and experience. The kinds of training required are identified in terms of three categories of personnel: mission operations personnel, NASA support personnel, and NASA administrative personnel. Gross training requirements by subject area typical of those to be implemented by the Phases C and D contractor are defined for the levels of training and personnel categories noted.

Table 6-1 shows a comparative overview to provide insight to the planning and training normally completed during Program Phases B, C, and D.

Table 6-1. Comparative Overview of Training Phases B, C, and D

Item	Program Phase B	Program Phase C	Program Phase D
Training plan	Preliminary plan definition, contents, and format. Baseline training requirements, and concepts.	Specific training and equipment requirements. Supporting training documentation.	Plan implementation for service as contracted. Revise as required.
Briefing and training	Concepts and usage defined.	Completed course syllabus and initial briefings.	Conduct formal briefings and courses.
Class sizing	Initial estimate of personnel training hours	Establish final hours and number classes	Revised as required.

6.3 STATION CREW TRAINING

6.3.1 CREW TRAINING PLANNING

The scope of crew training discussed herein will be increased in Phase C with expansion of briefing needs, practice required, and test or checkout participation anticipated for station crews to acquire the knowledge and skills for space station management and operation. Coverage is general because most of the detailed crew planning effort in Phase C is to be prepared by the contractor in other document form to reduce the training plan size. These informal planning documents may be used by NASA and the contractors to define detailed part task, mission simulation, network tie-in simulation, and real-time simulation exercises for space station crews and mission management personnel. The informal documents are scheduled and controlled directly by the crew training plan or by the contract-imposed reports prepared by the contractors. It is recommended that NASA accomplish the final detailed station crew training planning with crew participation in order to integrate station crew training with their other real-time activities.

6.3.2 CREW DEFINITIONS

The on-orbit station crew (all members) is divided into three functional categories:

1. Flight operations crew: personnel responsible for Station operation, management, and maintenance (commander, flight controller, and systems engineer)

2. Support technicians: experiment and station support electronics, mechanical, biology, and medical skills personnel

3. Experiments personnel: individuals responsible for the conduct or experiments, the medical doctor, biochemist, agronomist, etc.

6.3.3 GENERAL CREW SELECTION

Station crew personnel selection, the periods during which they are required, the cross-training or multiple disciplines needed, the depth of training, training lead time, and physical preconditioning of crew members must be based on phasing of the functional program elements (FPE's) scheduled on-orbit, the degree of FPE automation, and the shuttle system available for crew transport (i. e., low, medium, or high boost and entry g forces). With lower forces, the number of individuals capable of functioning in space is broadened, permitting selection of many highly specialized scientists who might otherwise be ineligible. FPE phasing versus the disciplines recommended for this study is provided in DRL-68, Vol II, SD 71-217-2, MSS Preliminary Systems Design (Operations and Crew Analysis) Station Program Operations Plan.

6.3.4 GENERAL CREW REQUIREMENTS

Crew members may be astronauts with multidiscipline backgrounds or scientific community personnel with minimum space and space station knowledge, skills, and physical preconditioning. In general, scientific community personnel must have the modular space station knowledge and skills to survive, alone if necessary, with minimum station management and operations for the period required for shuttle rescue.

NASA agencies and Government organizations from which NASA draws personnel have many of the multidisciplined science and pilot skills required for the operation of a MSS. The general training requirements for experiments crew members are shown in Paragraph 6.4. The general training requirements for experiments crew members are summarized in Table 6-2. Technical briefing requirements specifically tailored for the needs of the flight operations crew for station subsystem operation and management are shown in Table 6-3.

6.3.5 GENERAL REQUIREMENTS AND ASSUMPTIONS

The following items represent the contractor's basic concept for crew training:

1. During the various phases of station buildup, special assembly crews consisting of at least two members are required on an intermittent basis for activation, checkout, and maintenance of the module cluster. These individuals require special training and knowledge of both the shuttle and space station modules.

2. Selection of initial crews is based on qualifications determined by the skills and disciplines needed to condition, operate, and support the space station first and then the FPE's as time, skill, and disciplines allow. Initial crew makeup consists of three operations persons, two support persons, and one scientist. Average workload allocations for the initial station should approximate 40 percent of the available man-hours for vehicle operations and 60 percent for FPE activities.

Table 6-2. General Training Course Requirements for Experiment Crew Members

Course Area	Contents	Duration (hours)	Unique Training Equipment and Facilities
Space Station design overview	Station functions Subsystem functions and design Standard operations and procedures Maintenance concept and emergency procedures	50 to 75 (approximately 30 hours spent in mockup or model)	Full-scale station mockup (course should include, where possible, tours of CAV or flight modules)
Space Station experiment program overview	Integrated introduction to program Current Station experiment program Future Space Station experiment, application, and exploration plan	30 to 50	None
Space Station personnel	Personnel organization Individual responsibilities and duties	10	None
Space orbiter design overview	Orbiter user overview Transport capabilities User standard and emergency procedures	35 to 40	Full-scale shuttle mockup including station interfaces at berthing port (course should include tour of flight vehicle).
Information subsystem user orientation	ISS capability-overview ISS design functions Operations	60 to 80	Operational simulator required
Environmental control and life support subsystem user orientation	ECLSS capabilities overview ECLSS design overview Design and use of: Food storage and preparation Personal hygiene Dining/recreation Waste management Atmosphere control Emergency procedures	50 to 60	Full-scale mockup—habitability features toilet, hygienic, food preparation & sleep facilities (CAV)
Shirtsleeve performance in zero-g	Theoretical background in effects of acceleration Standard task-performance experience in simulated zero-g (emphasize experience with restraint devices and mobility aids)	20 (includes 10 hours in simulated space conditions)	Neutral buoyancy facility Artificial-g centrifuge facility Partial mockups of critical Station crew interfaces
Pressure suit performance*	Suit design, care, & maintenance Standard and emergency operations in simulated zero-g Extravehicular activities (emphasis on use of mobility aids)**	10 (includes 2 to 5 hours in suit assembly)	Pressure suits and suit-loop control simulator Partial-vacuum pressure vessel Partial mockups of critical Station crew interfaces

*Required primarily in conjunction with shirtsleeve performance, not for on-orbit activities
**Special exceptions only

Table 6-3. Flight Operations Crew Subsystem Technical Briefings

Briefing Number	Briefing Title	Briefing Length (hours)
SXXX	Modular Space Station Electrical Power Subsystem Technical Briefing	24
SXXX	Space Station Information Subsystem Technical Briefing	60
SXXX	Space Station Environmental Control and Life Support Subsystem Technical Briefing	36
SXXX	Space Station Structural Subsystems Technical Briefing	36
SXXX	Space Station Crew Habitability Subsystem Technical Briefing	18
SXXX	Space Station Reaction Control Subsystems Technical Briefing	18
SXXX	Space Station Guidance and Control Technical Briefing	36
SXXX	Shuttle Technical Briefing	18

3. Crew mixes after the initial flights tend toward fewer astronaut-engineering personnel and more scientific personnel. This approach is possible because of maximum use of automatic subsystems, automatic redundancy, minimum schedule maintenance, increased flight crew proficiency in handling more operations, improved on-orbit procedures, and low-energy boost and return via the shuttle.

4. On-orbit training of individuals who are not part of the required crew complement is precluded since on-orbit experiment time and manpower are extremely valuable. Earth-based training supplemented with closed-circuit television (CCTV) or voice down-link

data from on-orbit crewmen is considered to be an efficient approach to providing replacement personnel for station management and operations.

5. Each crew participates in the training of replacement crews by providing follow-on training information while on orbit and after return from the station tour of duty.

6. The crew commander and other crew members in training, as well as NASA management, decide when the crew members have achieved the skill and depth of training necessary for successful operation of the station and experiments missions.

7. It is estimated that approximately 40 percent of the station crew members will repeat their tours of duty provided no physiological or psychological reasons for restricting repeat tours are discovered in the Skylab program or other space research.

8. With no repeating of tours, planned mission requirements for a ten-year period require the training of 240 men. Training of an additional 24 men (approximately 10 percent) is required to allow for contingencies. Assuming that 40 percent of the 240 mission personnel repeat their tours, only 144 crewmen plus the 24 contingency personnel, or 168 total station crewmen, require initial training. Some refresher training is required for the repeat crewmen. Over the ten-year station lifetime, the number may be somewhat lower, to the extent that contingency personnel are used as station crew members.

9. The training period for a crew is completed 30 days before the crew is scheduled to go on orbit. This scheduling allows time for the crew to move to the shuttle launch site, prepare personal effects for the on-orbit tour, and observe final shuttle operations, cargo loading, FPE preparation, and other prelaunch operations.

10. It is recommended that qualified candidates within the required scientific disciplines be enlisted by NASA and trained for specific FPE and space stations skills, tasks, and interfaces; shuttle interfaces; station habitability; environmental acclimation; and familiarization with station operations to a Training Level 2 understanding minimum. (Training levels are explained in Paragraph 6-4 of this section.) The experiment coordinator is trained in station operation and management to Level 3 to facilitate communication with the spacecraft commander should unplanned conflicts arise

between station requirements and experiments requirements. It appears that approximately three month's lead time is required to prepare support technicians and experiments personnel for a space station tour.

6.3.6 CREW PREPARATION

Following selection of the station crew commander, station training is initiated for the other flight crew personnel, support technicians, and experiment personnel. The training period for a crew is approximately eight months, time-phased by discipline and functional category. Concurrently with the early station training of the flight crew personnel, FPE training of specialized experiments personnel is implemented. All Station and FPE training is completed 30 days prior to crew launch. Figure 6-1 shows a typical crew preparation timetable for replacement crews. The precise lead time cannot be based on the figures shown, however, since the scope and duration of courses have yet to be established.

Crew training preparation time varies for space station and FPE activities and for total program participation. The initial crews have a completely unique task to perform in a unique environment, i.e., they must perform assembly tasks, and engineering evaluations of the station. In addition, their training is different from that of subsequent crews because

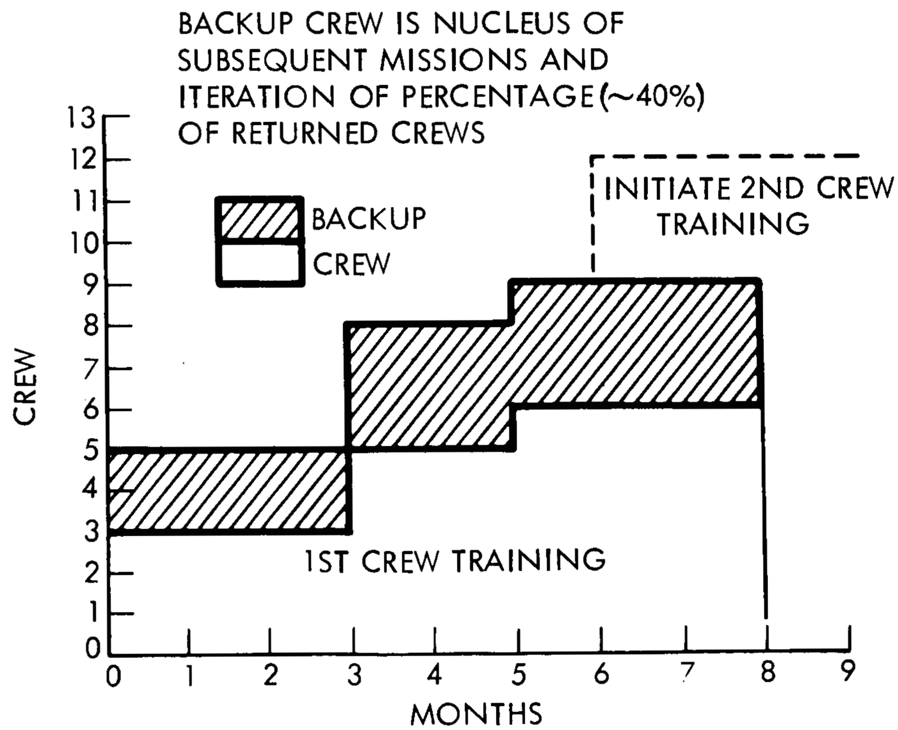


Figure 6-1. Typical Crew Preparation Timetable

they have the opportunity to participate in prelaunch equipment development, testing, and checkout. The mode of training for FPE's may vary with the following circumstances:

1. FPE flight hardware is available on the ground for crew training.

2. The FPE flight hardware is unavailable for crew training because it is on orbit before crew selection or because it is scheduled for launch after the crew arrives on orbit.

3. FPE flight hardware has been on orbit and its functional usage is changing, thereby changing the training requirements and possibly the skills for the replacement crew(s).

6.3.7 GENERAL OBJECTIVE

In general, the station crew operations and habitability goals for the planned ten-year mission is to sustain a normal daily routine as though at an isolated earth-based laboratory with complete autonomy, except for occasional logistics replenishment. The primary differences between the earth-based laboratory and the space station lie in station accessibility, zero-g environment, advanced station subsystems, and flight control operations.

Crew preparation for the space station may not present the same intense training peaking problems encountered in Apollo, where group-trained astronauts were required to accomplish integrated manipulations for space vehicle operation and systems management. Group training for the station is minimal, compared with that for Apollo, except for interface requirements between scientific and station operation personnel. Common knowledge of both FPE and station capabilities and demands is required when, for example, an astronomer requests a change in the attitude of an FPE or the station to realign a telescope.

6.3.8 CREW TRAINING PHASING

Recommended initial training of station crews is shown in Figure 6-2 in program and training milestone format. Milestones are indicated to provide visibility during the MSS and FPE design review, test monitoring, station acceptance testing, prelaunch crew participation, and station crew briefings.

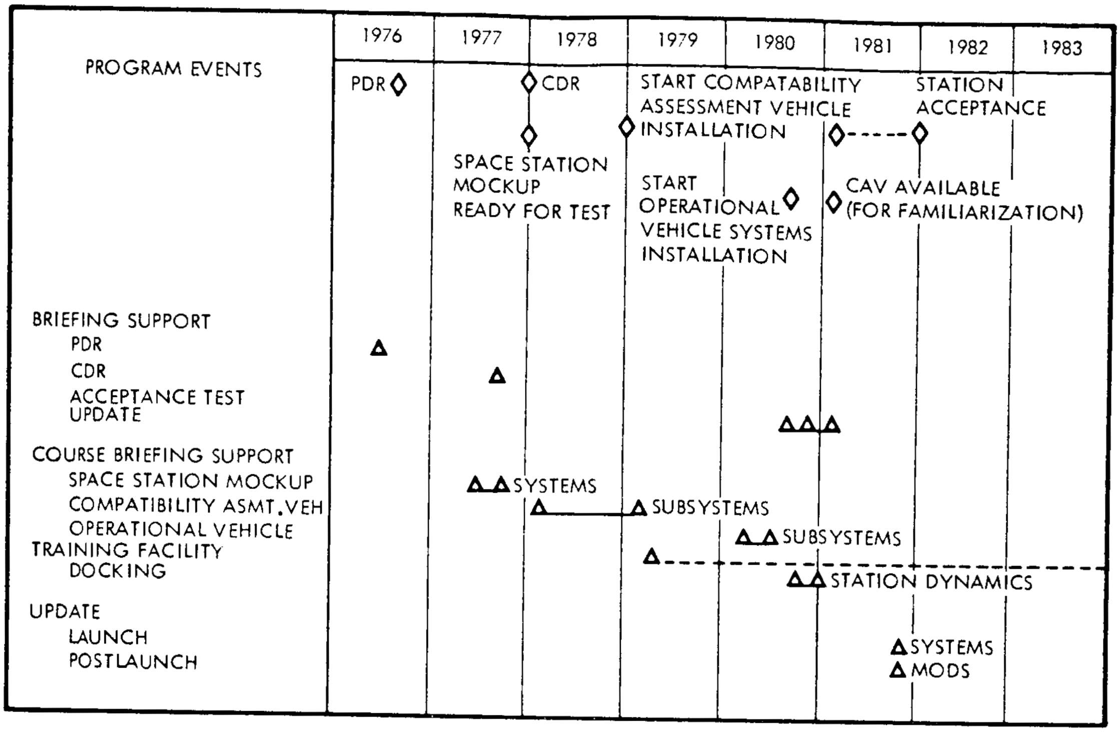


Figure 6-2. Planned Initial Crews Training Phasing

6.4 REQUIREMENTS

Training is required for successful accomplishment of the operation and management tasks for the modular space station and experiments throughout the period from prelaunch to full activation of all systems. This section of the plan contains the contractors recommendations for NASA training of MSS crews, mission management, and general support personnel. Also discussed are crew training equipment, acceptance testing monitoring, and prelaunch countdown participation.

6.4.1 CONTRACTOR INVOLVEMENT

The contractor will establish the initial requirements for training and equipment, prepare training equipment and materials and conduct training, within manpower constraints, on contractor-developed hardware as directed.

The extended program development and operational duration suggests that NASA consider the cost saving of phasing the contractor out of the NASA training program and conducting the training itself on contractor equipment. Contractor participation may be retained in a minimal advisory capacity on changes in training.

6.4.2 PERSONNEL CATEGORIES

To identify the kinds of training required, the types of NASA personnel assigned to the MSS program are grouped into three categories projected from Apollo experience: NASA mission operations, NASA support operations, and NASA general operations.

The NASA mission operations category includes three elements: (1) station crew members who perform as station and experiments management and operator personnel on orbit; (2) mission management personnel who perform mission planning, flight operations, experiments planning, experiments operation management, logistics inventory management, station tracking, communications, launch control, and generally provide preplanned and real-time on-orbit support to the modular space station and shuttle; and (3) flight support personnel who supervise the design and development of simulators and training equipment, operate the equipment, conduct crew training, supervise crew station and FPE procedures development, and prepare crew station and FPE procedures.

The NASA support category includes three elements: (1) design and development personnel who direct and monitor modular space station subsystems design activities; (2) test and evaluation personnel who develop subsystem simulation to evaluate and test subsystem hardware and who monitor the integration of station subsystems; and (3) reliability, quality assurance, quality control, and safety personnel who prepare reliability criteria and monitor and inspect the station during assembly and acceptance testing.

The NASA general category includes personnel who have tasks that are generally administrative and who do not necessarily have direct interfaces with the mission or space station.

Four levels of training are defined to indicate the required depth of training in the matrix forms used in this document.

1. Level 1, Orientation. An identification of the major units of a system and of the subsystem functions (cursory introduction to the subject).

2. Level 2, Familiarization. A functional and operational analysis of the subject showing significant data flow, interfaces, and operator action.

3. Level 3, Mechanization. A detailed analysis to provide sufficient normal and contingency operating characteristics and procedures that will enable equipment malfunctions to be determined and remedial action to be recommended.

4. Level 4, Experience. Specific experience in an environment similar to the operational tasks. Level 1 through 3 classroom training and related practical experience are always a prerequisite for Level 4 activity.

The time required to achieve a given level of training varies from category to category because of differences in subject matter; therefore, the relationship between level and course length is not constant for all courses provided.

6.4.3 TRAINING REQUIREMENTS

Approach

This subsection of the plan indicates the level of required training by subject area and, in some instances, for several personnel elements within each personnel category. Detailed training requirements are the basis for all training courses and the development of training equipment.

The process by which detailed requirements are provided is heavily dependent on mission and operation functions, the crew interface with these functions, and the man-machine trade decisions made during design definition. Crew tasks and skill requirements are based on mission and operational functional analyses and on hardware management and operation requirements. The crew tasks are broken down into elements of work; and from these data, the tasks and elements are logically grouped to identify requirements for training, training equipment, graphics, courses, and course materials.

The following are conditions that relate to the generation of Phase C contractor-prepared training requirements:

1. Trained personnel are the ultimate responsibility of line organizations (NASA or contractors).

2. The contractor is involved primarily with training requirements for the contractor-developed equipment.

3. NASA organizations, knowing their total responsibility, identify the general areas that require contractor training assistance.

4. The contractor conducts training analysis as required to define all NASA training courses and training equipment.

5. Line organizations (NASA or contractors) approve contractor-prepared training program plans resulting from their general requirements.

Requirement Matrixes

The matrixes in this section provide the general training subject areas for personnel elements within the personnel category. The systems requirements Book (SD 71-203) matrixes were developed from modular space station with consideration of present NASA organizational functions.

The left column of the matrixes is a list of functional groups within a personnel category or element. The top column is a listing of training subject areas for the entire category. The numbers in the body of the matrix define the first estimate of the required training level for the subject and associated personnel group. The training levels are defined in the preceding subsection.

Station Training Requirements Matrix (Crew)

Table 6-4 is a matrix of required MSS crew training. Some of the subject areas and personnel categories indicated in the matrixes are further defined in the following paragraphs.

"Station Briefings" consist of classroom briefings to provide a Space Station Program overview. They are started early in the program and are repeated as required for new program crew personnel. "Station Subsystem Briefings: are classroom courses on the operation of each of the station subsystems. The level of detail in the subsystem briefings is specifically tailored for the station crew.

"Station System Management Skills" are classroom courses and trainer practice in tasks such as inventory system operation and station orbit makeup. These tasks are long-range planned mission situations involving minimal manipulation by the crew. "Station Operations Skills" consist of classroom courses and trainer practice in tasks such as the MSS attitude change for earth-resources target of opportunity, station communications to earth, etc. These situations are usually immediate and dynamic and require considerable manipulation by the crew. The same basic explanation applies to the laboratory experiment subject areas with similar titles.

"Station Module and Laboratory Experiment Acceptance Test" subject areas on the matrix involve classroom courses on subsystems and their operation for permitting station crews to indicate their design and operation preferences wherever options are available during test participation.

"Delta Briefings" are normally short classroom presentations given at the request of crew members to update their knowledge of the station. The classroom presentations provide only change data in subsystem design or operation, assuming the crew members are already proficient and knowledgeable on the subject.

The personnel category "Shuttle Specialist" is provided for individuals or small groups that may be sent to the space station on orbit temporarily to conduct a complex station modification (e. g. , experiment module modification, earth-survey sensor exchange) without disrupting the normal crew operations. This group also includes those required to accomplish station or experiment-module repairs that require special skill, tools, or materials not on orbit. These individuals require special training and knowledge of both the shuttle and space station modules.

Table 6-4. Station Training Requirements Matrix, NASA Mission Operations Category, Station Crew Element

Personnel	Science of Space Flight Briefings	Environmental Acclimation	Recovery and Survival	Shuttle Interface Briefing	Experiments (Includes Disciplines Cross Training)	Station Design Reviews (PDR, CDR)	Station Briefings	Station Subsystem Briefings	Station Systems Management Skills	Station Operation Skills	Laboratory/Experiments and Cargo Design Reviews	Laboratory/Experiment Briefing	Laboratory Subsystem Briefings	Laboratory Systems Management Skills	Laboratory/Experiments Operations Skills	Experiment Data Gathering and Management	Station Modules Acceptance and Test	Laboratory/Experiments Acceptance and Test	Station Prelaunch and Countdown	Delta Briefings	Mission Procedures and Rules
	Required Level of Training by Subject Area																				
First and Second Station Crew Members																					
Flight	*	*	*	*	3, 4	2	2	3	4	4	2	2	3	4	4	3	4	3	4	2	4
Support	*	*	*	*	4	2	2	3	4	4	2	2	3	4	4	4	4	4	4	2	4
Scientific	*	*	*	*	4	1	2	3	4	4	1	1	3	4	4	4	4	4	4	1	4
Subsequent Station Crews																					
Flight	*	*	*	*	3	NA	2	3	4	4	2	2	3	4	3	3	*	2	NA	2	4
Support	*	*	*	*	4		2	2	2, 3	4	2	2	3	4	4	4	*	4	NA	2	4
Scientific	*	*	*	*	4		2	2	2, 3	3	2	2	3	4	4	4	*	4	NA	1	4
Repeat Station Crew Members	*	*	*	*	3, 4	NA	2	2, 3	2, 4	2, 4	2	2	3	3, 4	3, 4	NA	NA	2, 4	NA	2, 3	3, 4
Shuttle crews																					
Flight	*	*	*	NA	NA	2	2	2	2	2	2	1	2	NA	NA	NA	1		*	1	4
Specialists	NA	*	*	NA	3, 4	NA	2	3	NA	4	*	1	3	NA	4	1	1		NA	NA	1

NOTES: Asterisk (*) denotes training level to be determined by NASA.
NA denotes not applicable.

Mission Management Matrixes

Because the on-orbit space station crew operations are performed on a normally routine schedule, the support aspects of the program also should be normally routine.

The current NASA qualification training program for mission control center (MCC) and launch control center (LCC) personnel is readily adaptable for use in the MSS program for mission management site (MMS) personnel. A significant difference between the training of MSS support and current program support is the declining need for on-orbit, multishift, real-time monitoring of the station by the mission management site because of the autonomy and single-shift operation of the station.

After the initial mission management site operations for space station module launches and monitoring of initial operational conditions, MMS personnel tasks shift to the long-term functions of inventory management, experiment planning, experiment management, and software preparation for station and experiments changes in capability and purpose.

Minimum capability must be retained to launch and retrieve the shuttle and to respond to station crew requests for specialized technical support in unusual station operations or emergencies. This callup support may be provided by the cadre of personnel who perform modification engineering, software verification, maintenance, and returned crews awaiting further assignment.

Tables 6-5, 6-6, and 6-7 are training matrices for the MMS administrative personnel. Table 6-8 is the training matrix for the general category of personnel.

Station Crew Training Requirements

The scope of MSS crew training is indicated in Tables 6-9 through 6-38. Prepared to correlate station, crew members, and required skill types, the tables contain nomenclature for crew members and tasks generally matching that used to define skills in DRL-68 Vol II, SD 71-217-2, MSS Preliminary Systems Design (Operations and Crew Analysis). The tables present skill types versus background and general training, duration of training courses, major training equipment, and experiments supported. The "General Training Required" column refers to the "Course Area" column by title in Table 6-2.

Table 6-5. Modular Space Station Training Requirements Matrix, NASA Mission Operations Category, Mission Management Element

Personnel	Orbital Mechanics	Shuttle Launch Vehicle Systems and Dynamics	Shuttle Systems and Dynamics	Shuttle Launch and Recovery	Station Briefings	Station Dynamics	Station Subsystem Courses	Laboratory/Experiment Briefings	Laboratory Subsystems Courses	Experiment Data Gathering and Management	Station and Shuttle Prelaunch Countdown	Station On-Orbiter Monitor	Lab/Exper Module Preparation and Servicing	Cargo Preparation and Servicing	Network System Operation	Network Systems Maintenance	Mission Procedures and Rules	Delta Briefings	Contractor Configuration Management
	Required Level of Training by Subject Area																		
Mission Management Site																			
Mission planning	*	*	*	*	2	2	1	1	NA	1	2	1	1	1	*	*	3	1	1
Flight Operations mgmt	*	*	*	*	2	4	3	1	1, 2	1	4	4	4	4	*	*	4	2	NA
Logistics inventory mgmt	NA	NA	*	NA	1	NA	3	1	NA	1	2	NA	2	2	NA	*	3	1	2
Experiments operations planning	*	NA	*	NA	2	2	3	2	3	2	2	NA	3	2	*	NA	4	2	2
Experiments operations mgmt	NA	NA	*	*	2	NA	3	2	1	4	2	2	2	2	*	NA	3	1	1
Mission Support Site																			
Tracking	*	*	*	*	1	4	2, 3	1	NA	1	4	4	NA	NA	*	*	4	2	NA
Communications link	8	*	*	*	1	1	2	2	NA	1	4	4	NA	NA	*	*	4	2	NA

NOTES: Asterisk (*) denotes training level to be determined by NASA
NA denotes not applicable.

Table 6-6. Modular Space Station Training Requirements Matrix, NASA Mission Operations Category, Crew Support Element

Personnel	Orbital Mechanics	Shuttle Systems and Dynamics	Shuttle Launch and Recovery	Station Briefing	Station Dynamics	Station Subsystem Courses	Laboratory/Experiment Briefings	Laboratory Subsystems Courses	Experiment Data Gathering and Management	Network Systems Operation	Simulators and Trainers, Systems (Station)	Simulators and Trainers, Operation (Station)	Mission Procedures and Rules	Delta Briefings
	Required Level of Training by Subject Area													
Crew Training														
Training Coordinators	*	*	*	2	3	3	2	3	2	3	3	4	2	2
Simulation Development	*	*	*	2	1	2	2	2	1	1	1	2	NA	1
Crew Procedures Development	*	*	*	2	3	3	2	3	2	3	3	3	2	2
	*	*	*	2	3	3	2	2	1	1	1	2	3	2

NOTES: Asterisk (*) denotes training level to be determined by NASA.
NA denotes not applicable.

Table 6-7. Modular Space Station Training Requirements Matrix, NASA Support Category, Design, Test, and Quality Assurance Element

Personnel	Required Level of Training by Subject Area: Station Design Reviews (PDR, CDR)	Station Briefings	Station Subsystem Courses	Lab/Exper and Cargo Module Briefings	Laboratory Subsystems Courses	Lab/Exper and Cargo Module Servicing	Station Servicing Equipment Briefings	Test Vehicle Development (CAV, MSV)	Acceptance Test (Procedures)	Contractor Drawing System	Contractor Configuration Management
System design and development engineering	2	2	3	2	3	3	3	3	2	1	1
Test and evaluation engineering	1, 2	2	3	2	3	3	3	3	3	1	2
Reliability engineering and quality assurance	-	2	2, 3	2	2, 3	2	2	1	2	1	2

Table 6-8. Modular Space Station Training Requirements Matrix, NASA General Category, Administrative Element

Personnel	Required Level of Training by Subject Area					
	Launch Vehicle Configuration	Space Station Mission	Mission Management Operations	Acceptance and Launch Operations	Station Briefings	Experiments Briefings
Management						
MSC	1	2	2	1	1	1
MSFC	2	2	2	1	1	1
KSC	2	1	1	2	1	1
Headquarters	1	2	1	1	1, 2	1, 2
Resident offices	1, 2	2	1, 2	1, 2	1, 2	1, 2
Test sites	1, 2	2	1	2	2	2
Air Force liaison	1	1	1	1	1	1

Table 6-9. Crew Training Requirements for Biology Laboratory Technician, Skill Type 1

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks 1. Prepare, set-up and checkout experimental/ support equipment. 2. Perform caretaker duties for all living organisms, plants and animals. 3. Assist in experimental operations including data correction. 4. Refurbish and service animal cages and support systems.	Specialty: Biology Research Assistant Academic Background: BS or MS in Biology or Biochemistry, Major course work should have been laboratory/analytical/ research-oriented. Other Experience: 3-5 years as research assistant in biology, bio-science, biochemistry or related laboratory.	Special Training Courses FPE/Experiment a. Objectives b. Set-up experimental operations, and data collection c. Sample and data preparation d. Refurbishment and servicing for experiment e. Corrective maintenance	150-200	Biology laboratory facilities	FPE's MS-1 LS-(2-5)	Station design Station experiment program Station personnel ECLSS user orientation Shirtsleeve performance
Secondary Tasks 1. Package equipment, specimens, samples, and physical data for return to ground.		Special Briefing Principal investigator briefings	40-50	Biology laboratory facilities		
2. Perform/assist corrective maintenance tasks. 3. Deactivate/terminate experimental operations.		Other Special Experience Team training exercises with biologist and electro-mechanical technician assigned to FPE	30-60	Station functional mockups		

Table 6-10. Crew Training Requirements for Microbiological Technician, Skill Type 2

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks	Specialty: Microbiology	Special Training Courses			FPE:	
1. Prepare, set-up, and checkout experimental and support equipment and specimens	Academic Background: PhD in biology, major course work in microbiology, molecular genetics, bio-physical cytology, embryology, biophysical chemistry	1. Space Biology course on effects of space environment (zero gravity, radiation, atmosphere, etc.) on living organisms - plants, animals, microorganisms. Review of all relevant research results	Refresher course (approximately 50 hours)	None	LS-(2-5)	Station design Station experiment program ECLSS user orientation Shirtsleeve performance
2. Activate experimental operations, monitor results, and perform "ad lib" research tasks	Other Experience:					
3. Evaluate data and discuss with PI's on ground	6-10 years' experience in research microbiology. Broad range of microorganisms should have been included	2. FPE/Experiment	80-100	Biology laboratory facilities		
4. Modify experiments as required		a. Objectives				
Secondary Tasks		b. Set-up, experimental operations, and data collection				
1. Deactivate experiment and package data/specimens/equipment for return to ground		c. Data analysis/sample and data preparation				
		d. Ground support capability				
		Special Briefing				
		1. Principal investigator briefings	30-50	Biology laboratory facilities		
		2. Biology laboratory technician duties and capabilities	20-30			
		Other Special Experiences				
		Team training exercises, with Biology laboratory technician and electro-mechanical technician assigned to same FPE	20-30	Station laboratory mockup. Biology laboratory facilities		

Table 6-11. Crew Training Requirements for Biochemist, Skill Type 3

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks: 1. Prepare experiment and set-up equipment. 2. Perform laboratory support tasks, as required in: a. Biological or medical analysis b. Life support systems organic or inorganic tests c. Metallurigial analysis 3. Support analysis of experiment data in above areas and, as required in geochemistry analysis.	Specialties: (as required) a. Biochemistry b. Geochemistry c. Organic/inorganic d. Chemical Engineering Academic Background: Masters degree in chemistry with major course work in one or more of the above specialties. Other Experiences: 5 or more years experience in above area(s).	Special Courses: FPE Experiment Requirements: a. Objectives b. Set-up, Checkout operators and data collection c. Refurbishment d. Job and analysis equipment Special Experience: Team training on FPE's supported	150-175 40-50	Hard mockups or prototype FPE and laboratory equipment.	Subsystems ECLSS FPE's LS-(2-5)	Station design Station experiment program ECLSS user orientation Shirtsleeve performance

Table 6-12. Crew Training Requirements for Physiologist, Skill Type 4

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks	Specialty	Special Training Courses			FPE	
1. Prepare, set-up and checkout experimental/ support equipment	Physiologist	1. FPE/Experiments	100-150	Module Mockup-Life Sciences Laboratory	LS-(2-5)	Station design
2. Prepare anatomical specimens for gross and microscopic examination	Academic Background	a. Objectives				Station experiment program
3. Evaluate data and discuss with PI's on ground.	PhD in physiology studies should include role of gravity in life process of mammals	b. Set-up and data collections				ISS user orientation
Secondary Tasks	Other Experience	c. Ground support capability				ECLSS user orientation
1. Perform laboratory maintenance and animal care	5-8 years experience with research in effects of space environment on animal performance and behavior	2. Life Sciences Laboratory design	50-100	Part-task trainers		Shirtsleeve performance
		a. Functional design				
		b. Physical design				
		c. Operations				
		d. Maintenance				
		Special Briefings				
		1. Principal investigator briefings	50-75			

Table 6-13. Crew Training Requirements for Astronomer/Astrophysicist, Skill Type 5

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks: a. Prepare for operations and checkout of astronomy FPE's. b. Operate and supervise others operating astronomy sensors. c. Evaluate data and consult with PI's regarding sensor operation and modification. Secondary Tasks: a. Direct and assist all astronomical equipment refurbishment tasks, servicing and replacing FPE consummables. b. Direct and assist the packaging of data and replaced equipment for return to earth. c. Calibrate optical systems as required. d. Assist electro-mechanical technician in corrective maintenance tasks.	Specialty: Astronomy Academic Background: PhD in astronomy with major course work in astrophysics, spectroscopy, astrophotography, solar UV/X-ray, stellar UV energy, and IR Other Experience: 4-6 years in research	Special Training Courses: 1. FPE/Experiment Requirements a. Objectives b. Set-up and operation c. Data collection d. Data analysis e. Calibration f. Maintenance and servicing	150-200 hours	1. Station mockup, visual aids for subsystem data, and emergency procedures 2. FPE hard mockups or prototypes, plus visual aids	FPE's A-1, A-2, A-3, A-4, A-5, A-6	Space station design Station experiment program ISS user orientation Shirtsleeve performance ECLSS user orientation

Table 6-14. Crew Training Requirements for Physicist, Skill Type 6

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks 1. Prepare, set-up and checkout experimental equipment on RMS and Station 2. Monitor experimental data returns and control progress of operations 3. Evaluate data verify experiment validity and discuss with ground PI	Specialty: Fluid physics Academic Background: PhD in physics, major course work in fluid physics, thermo-dynamics and kinetics, and laboratory research Other Experience: Preferably 4-5 years' experience as research physicist in fluid mechanics	Special Training Courses 1. FPE/Experiment a. Objectives b. Design and characteristics c. System set-up and data collection d. Data evaluation/preparation e. Ground support capability	75-100	Mockups Station monitoring console	FPE's P-1, P-2, T-1, P-4	Station design Station experiment program ISS user orientation ECLSS user orientation Shirtsleeve performance
Secondary Tasks 1. Terminate experiment operations 2. Compress data and prepare for return to ground		Special Briefing Principal investigator briefings	50-60	None		
		Other Special Experience Team treaming exercises with personnel assigned to same FPE	20-30	Part-task trainers and simulators		

Table 6-15. Crew Training Requirements for Nuclear Physicist, Skill Type 7

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks 1. Prepare, set-up and checkout experimental equipment on Station 2. Monitor experimental data returns and control progress of operations 3. Evaluate data verify experiment validity and discuss with ground PI	Specialty: Nuclear physics Academic Background PhD in physics, major course work in cosmic-rays, and laboratory research Other Experience: Preferably 4-5 years' experience as research physicist in study of high-energy cosmic radiation.	Special Training Courses 1. FPE/Experiment a. Objectives b. Design and characteristics c. System set-up and data collection d. Data evaluation/preparation e. Ground support capability	75-100	Mockup cosmic-ray physics laboratory	FPE's P-3	Station design Station experiment program ISS user orientation ECLSS user orientation Shirtsleeve performance
Secondary Tasks 1. Terminate experiment operations 2. Compress data and prepare for return to ground		Special Briefing Principal investigator briefings	50-60	None		
		Other Special Experience Team training exercises with personnel assigned to same FPE	20-30	Part-task trainers and simulators		

Table 6-16. Crew Training Requirements for Photographic Technician/Cartographer, Skill Type 8

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks 1. Process all still and movie film and photographic plates 2. Provide photo interpretation for use in map production Secondary Task Assist in aligning, calibrating, and servicing optical equipment	Specialty: Photographic processing and map construction Academic Background: BS in mechanical engineering, major course work in optics, sensors, and photometry/photography. Other Experience: 4-8 years work experience in photographic systems and map production	Special Training Courses 1. Space Station Photography a. Still-film processing (35 mm and 70 mm) b. Movie film processing (16 mm, 35 mm and 70 mm) c. Photographic plate processing (9 x 9 and 9 x 14) d. Photometric analyses	75-100	Part-task trainers for all processors, editors, enlargers, etc.	Subsystems: Operations FPE's ES-1	Station design Station experiment program ECLSS user orientation Shirtsleeve performance
		2. FPE Optical Equipment Review of all optical equipment on station, and procedures for servicing, aligning, and calibrating	30-50	Part-task trainers		
		Special Briefings: Photographic processing and interpretation requirements for specific FPE's	50-75			

Table 6-17. Crew Training Requirements for Thermodynamicist, Skill Type 9

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks 1. Prepare, set-up and checkout experimental equipment on Station 2. Monitor experimental data returns and control progress of operations 3. Evaluate data verify experiment validity and discuss with ground PI Secondary Tasks 1. Terminate experiment operations 2. Compress data and prepare for return to ground	Specialty: Fluid Physics Academic Background: PhD in physics, major course work in thermodynamics and laboratory research Other Experience Preferably 4-5 years' experience as research thermodynamicist in study of boiling and condensing heat transfer mechanisms.	Special Training Courses 1. FPE/Experiment a. Objectives b. Design and characteristics c. System set-up and data collection d. Data evaluation/preparation e. Ground support capability	75-100	Physics and Chemistry Laboratory Mockup	FPE's P-4	Station design Station experiment program ISS user orientation ECLSS user orientation Shirtsleeve performance
		Special Briefing Principal investigator briefings	50-60	None		
		Other Special Experience Team training exercises with personnel assigned to same FPE	20-30	Part-task trainers and simulators		

Table 6-18. Crew Training Requirements for Electronics Engineer, Skill Type 10

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks	Specialty:	Special Training Courses			Subsystems	
1. Prepare, set-up and checkout station equipment	Electronic systems maintenance and operation	1. FPE Experiment requirements:	75-80	Hard mockups or prototype FPE's	Guidance and control	Station experiment program
2. Assist in experiment operations	Academic Background:	a. Objectives			ISS	ECLSS user operations
3. Refurbish and service electronic equipment	BS degree in Electronics with course work in systems operation and maintenance.	b. Set-up, checkout operations, and data collection			EPS	Shirtsleeve performance
4. Perform subsystem scheduled maintenance and servicing	Other Experience:	c. Refurbishment and servicing			FPE's	Pressure suit performance
5. Perform SS unscheduled maintenance which includes fault isolation, remove and replace defective components, checkout operations, and calibration as needed.	4 to 6 years experience on aircraft or spacecraft systems checkout, operation and maintenance.	d. Corrective maintenance			LS-1 and all with electronic equipment	
		2. Space Station Requirements	100-150	Space Station mockup		
		a. Subsystem activation, checkout, operation, servicing, fault isolation, remove and replace components, and calibration				
		3. Other Special Experience Training exercises with flight crew	30			

Table 6-19. Crew Training Requirements for Mechanical Engineer, Skill Type 11

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks	Specialty:	Special Training Courses			FPE's	Station design
1. Prepare set-up and checkout experimental/ support equipment.	Aerospace systems design, operation, and maintenance	Advanced technology and engineering operations FPE designs and methodology		FPE hard mockups or prototypes, plus visual aids	T-4, T-5	Station experiment program
2. Conduct engineering development operations.	Academic Background:					Station personnel
3. Calibrate and align equipment or systems as required.	Degree in mechanical engineering with emphasis or experience in Aerospace, Masters degree preferred.	Teleoperator deployment and retrieval	150-200 hours			ISS user orientation ECLSS user orientation
4. Prepare data on conduct of experiments.	Related experience in system dynamics, servomechanisms, optical systems, and systems maintenance.					Pressure suit performance
Secondary Tasks						
1. Refurbish and service FPE's as required.						
2. Supervise/perform corrective maintenance on FPE's.						

Table 6-20. Crew Training Requirements for Electromechanical Technician, Skill Type 12

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks	Specialty	Special Training Courses			Subsystems	
1. Prepare, set-up and checkout station or experiment equipment	Fluid-mechanical Systems	1. Subsystems	140-150	Station mockup	ECLSS	Station experiment program
	Academic Background	a. Functions		Laboratory	Crew	Shirtsleeve performance
2. Assist in experiment operations.	BS in Electromechanical Engineering; major course work in fluid dynamics, electrical power, maintainability.	b. Maintenance		Facilities	EPS	Pressure suit performance
		c. Test and checkout			RCS	
3. Maintain refurbish and service station and experiment support equipment		2. FPE/experiment	75-80	FPE prototypes	FPE's	
	Other Experience	a. Objectives			All with electro-mechanical equipment	
Secondary Tasks	3-5 years experience design, test, or maintenance engineering and aircraft or spacecraft systems maintenance.	b. Set-up, checkout and operations				
1. Package physical data, material specimens, and replaced equipment for return to ground		c. Refurbishment/ servicing				
2. Perform subsystem scheduled maintenance and servicing		d. Corrective maintenance				
		Other Special Experience	20-30			
3. Perform corrective maintenance operations.		Training exercises with flight crew				

Table 6-21. Crew Training Requirements for Medical Doctor, Skill Type 13

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks 1. Activate and operate medical/biological equipment 2. Perform medical checkout on all experimental subjects 3. Supervise collection and analysis of human specimens (blood, urine, etc.) 4. Evaluate data, review with ground personnel and modify experiment procedures as required Secondary Tasks 1. Assist in initialization of equipment and verification of operations 2. Prepare physical data, specimens, samples, records, etc., for return to ground	Specialty: Internal medicine or aerospace medicine. Research orientation essential. Academic Background MD degree, internship in internal medicine, aerospace medicine or cardiovascular research. Post-graduate studies should include research statistics and data analysis, aerospace medical research, and anthropometry. Other Experience 5-8 years in research oriented work; experience with and knowledge of medical instrumentation design and functions; some experience in practice of medicine desirable, preferably in military or paramilitary connection.	Special Training Courses 1. Aerospace Medicine; acceleration and Weightlessness, atmosphere, composition and temperature, toxicology, radiation, anthropometry, vestibular system, combined stresses, food, water, waste, vision, hearing and the human operator	Refresher course 50-75	None	Subsystems Crew FPE's LS-1	Space station design overview Space station experiment program Space Station personnel ISS user orientation ECLSS user orientation Shirtsleeve performance
		2. Medical Facility Design a. Functional design b. Physical design c. Operations d. Maintenance	75-100	MSS mockup		
		3. FPE/Experiment a. Objectives b. Set-up and data collections c. Data analysis/preparation d. Ground support capability	20-30	Biochemical laboratory facilities for demonstrations (Recommend use of NADC man-centrifuge)		
		Special Briefings Principal investigator briefings	10-20			
		Other Special Experiences Participate in/or review results of final equipment qualification tests	40-60	None		

Table 6-22. Crew Training Requirements for Optical Technician, Skill Type 14

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks	Specialty: Sensor systems operations and maintenance	Special Training Courses				Station design
1. Calibrate optical systems as required	Academic Background:	1. Sensor Systems	75-100	Visual aids/graphics	Subsystems:	Station experiment program
2. Prepare data and replaced equipment for return to ground.	EE degree with emphasis in optics, sensors, or systems engineering.	a. Large-scale optical systems			G&N ISS FPE's:	ECLSS user orientation
3. Assist electro-mechanical technician and mechanical engineer in corrective maintenance tasks	Other Experiences:	b. High energy sensors			ES-1 A-1, A-3	Shirtsleeve performance
	Optics and sensor equipment design and maintenance	c. IR/visible/ UV sensors				
		d. Environmental requirements				
		2. FPE/Experiments	100-125	Mockups of FPE's or prototypes		
		a. Objectives				
		b. Module design				
		c. Module/subsystem maintenance				
		Other Special Experiences				
		Team training exercises with Pilot/System Engineer and Mechanical Engineer assigned to same FPE's	20-30	Module mockups		

Table 6-23. Crew Training Requirements for Optical Scientist, Skill Type 15

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks 1. Activate and operate optical systems as required 2. Prepare data and replaced equipment for return to ground 3. Assist electro-mechanical technician and mechanical engineer in corrective maintenance tasks	Specialty: Sensor systems operations and maintenance Academic Background: PhD in engineering with courses in optics and optical systems and sensors and sensor systems control Other Experiences: Optics and sensor equipment design and maintenance	Special Training Courses 1. Sensor Systems a. Large-scale optical systems b. High energy sensors c. IR/visible/UV sensors d. Environmental requirements	75-100	Visual aids/graphics	Subsystems: G&N ISS FPE's: A-2, A-3, A-4	Station design Station experiment program ECLSS user orientation Shirtsleeve performance
		2. FPE/Experiments a. Objectives b. Module design c. Module/subsystem maintenance	100-125	Mockups of FPE's or prototypes		
		Other Special Experiences Team training exercises with astronomer and electromechanical technician assigned same FPE's	20-30	Module mockups		

Table 6-24. Crew Training Requirements for Meteorologist, Skill Type 16

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks 1. Prepare, set-up, and checkout experimental support equipment 2. Plan, integrate, and conduct supervise daily experimental operations 3. Screen, edit, correlate, enhance, and analyze data return 4. Compile and format data for ground and discuss with PI's	Specialty Meteorology Academic Background Ph. D. in meteorology with electrical course work in engineering (sensors/optics) Other Experience 8-10 years' experience in earth sciences	Special Training Courses 1. FPE/Experiments a. Objectives b. Module design c. System set-up and data collection d. Ground support capability	150-200	Module mockup Station/module interface monitor/control simulator	FPE: ES-1	Station design Station experiment program LSS user orientation ECLSS user orientation Shirtsleeve performance
		Special Briefings Principal investigator briefings	30-50	None		
Secondary Tasks 1. Deactivate/terminate experimental operations		Other Special Experiences Team training exercises with support personnel assigned to FPE	20-30	Module mockup Station module interface simulator		

Table 6-25. Crew Training Requirements for Microwave Specialist, Skill Type 17

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks	**Specialty**	**Special Training Courses**				
1. Set up and checkout millimeter wave communication and propagation system.	Microwave systems maintenance	1. COMM/NAV. FPE	100-150	COMM/NAV Research Facility Mockup	FPE C/N-1	Station design
2. Perform calibration and maintenance tasks on experiment equipment - receivers, transmitters, etc.	**Academic Background** EE degree with emphasis in optical or microwave sensor systems and laser radar	a. Experiment objectives b. System setup and data collection				Station experiment program ISS user orientation ECLSS user orientation
3. Reconfigure equipment for each test involving MSS	**Other Experience** 6-8 years work experience in microwave systems	c. Use of optical frequencies in space communications applications: (1) Space-to-ground (2) Space-to-space				Pressure suit performance
Secondary Tasks		**Special Briefings**				
1. Assist in evaluation of experiment data		Principal Investigator briefings	50-60			
		Other Experience				
		Use of remote sensing instruments aboard aircraft	10-20	Instrumented high altitude aircraft (C-135, B-52, etc.)		

Table 6-26. Crew Training Requirements for Oceanographer, Skill Type 18

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks	Specialty	Special Training Courses				
1. Prepare, set-up and checkout experimental/support equipment	Oceanography	1. Earth Surveys Overview	100-150	Visual aids/graphics	FPE	Station design
	Academic Background	a. Introduction to meteorology, geology/geodosy, agriculture/forestry, etc.			ES-1	Station experiment program
2. Plan, integrate and conduct/supervise daily experimental operations	PhD in oceanographic physics with course work in Electrical Engineering (sensors/optics)					ISS user orientation ECLSS user orientation
3. Screen, edit, correlate, enhance, and analyze data return	Other Experience	b. Earth surveys sensor design/operations				Shirtsleeve performance
	8-10 years' experience in earth resources disciplines	c. Sensor data evaluation/signature analysis				
4. Compile and format data for ground and discuss with PI's		2. FPE/Experiments	50-75	Module mockup. Station/module interface monitor/control simulator		
Secondary Tasks		a. Objectives				
1. Deactivate/terminate experimental operations		b. Module design				
		c. System set-up and data collection				
		d. Ground support capability				
		e. Module/subsystem maintenance				
		Special Briefings				
		Principal investigator briefings	30-50	None		
		Other Special Experiences				
		Team training exercises with electrical engineer and mechanical engineer assigned to FPE	20-30	Module mockup. Station module interface simulator		

Table 6-27. Crew Training Requirements for Physical Geologist, Skill Type 19

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks	Specialty:	Special Training Courses				
1. Prepare for operation and checkout Earth Surveys sensors, and monitor/control equipment on-board Station.	Geologist	FPE/Experiments	150-200	Module mockup Station/module interface monitor/control simulator	FPE ES-1	Station design Station experiment program LSS user orientation ECLSS user orientation Shirtsleeve performance
	Academic Background: PhD in geology, with courses in electrical engineering (sensors/optics).	a. Objectives b. Module design c. System set-up and data collection				
2. Initiate targeting sequences; monitor real time data	Other Experience:	d. Ground support capability				
3. Assist geographer in experiment operations and data evaluation.	6-8 years' experience in earth resources disciplines	e. Module/subsystem maintenance				
		Special Briefings Principal investigator briefings	50-75	None		
Secondary Tasks						
1. Perform all equipment refurbishment tasks - servicing and replacing film and other consumables		Other Special Experiences 1. Team training exercises with Earth Survey Scientist and Photo Tech/Cartographer	50-30	Module mockup Station/module interface simulator		
2. Package data and replaced equipment for return to ground						
3. Assist Electro-mechanical Technician and Test Engineer in corrective maintenance tasks.		2. Use of remote sensing instruments aboard aircraft	15-60	Instrumented high altitude (>50,000 ft) cargo-size aircraft (C-135, B-52, etc)		

Table 6-28. Crew Training Requirements for Photogeologist, Skill Type 20

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks	Specialty:	Special Training Courses				
1. Prepare for operation and checkout Earth Surveys sensors, and monitor/control equipment on-board Station.	Geologist Academic Background: Masters degree in geology, with courses in photometry/photography	FPE/Experiments a. Objectives b. Module design c. System set-up and data collection	150-200	Module mockup Station/module interface monitor/control simulator	FPE ES-1	Station design Station experiment program LSS user orientation
2. Process all still and movie film and photographic plates	Other Experience 6-8 years' experience in earth resources disciplines	d. Ground support capability				ECLSS user orientation Shirtsleeve performance
3. Assist geographer in experiment operations and data evaluation		e. Module/subsystem maintenance				
Secondary Tasks		Special Briefings	50-75	None		
1. Perform all equipment refurbishment tasks - servicing and replacing film and other consumables		Photographic processing and interpretation requirements for Specific FPE				
2. Package data and replaced equipment for return to ground		Other Special Experiences 1. Team training exercises with Earth Survey Scientist.	20-30	Module mockup Station/module interface simulator		
3. Assist Electromechanical Technician and Test Engineer in corrective maintenance tasks						

Table 6-29. Crew Training Requirements for Behavioral Scientist, Skill Type 21

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary	Specialty	Special Training Courses			FPE's	
1. Prepare equipment used for man performance tests	Human factors engineering	1. Aerospace medicine - referesher (short) course	50-75	None	LS-7	Space station design
	Academic Background:					Station experiment program
2. Conduct/supervise experiment recording of performance data (visual, motor, auditory, etc.)	Doctorate in experimental psychology or human factors (engineering degree)	2. Medical equipment design	50-75	Classroom mockups. Full operational simulator for extra-classroom exercises		Station personnel
		3. FPE/experiment	100-150			ECLSS user orientation
	Strong in experimental psychology, sensor mechanisms and behavior, performance evaluation	a. Objectives		Full operational simulators (except centrifuge)		Shirtsleeve performance
3. Evaluate data and discuss with PI's on ground		b. Set-up and data collection				Pressure suit performance
4. Modify experiments as required	Other Experience:	c. Data analysis/preparation				
Secondary	6-8 years' experience in aerospace medicine, or systems engineering research and/or design background	d. Ground support capability				
1. Deactivate equipment and package data equipment for return to ground		Special Briefing				
		Principal investigator briefing	80-100	See Special Training Course		
2. Assist medical doctor, as required in conduct/integration of behavioral tests		Other Special Experiences				
		Crew training exercises	20-30 hours	See Special Training Course		

Table 6-30. Crew Training Requirements for Chemical Technician, Skill Type 22

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks 1. Prepare experiment and set-up equipment. 2. Perform laboratory support tasks, as required in: a. Biological or medical analysis b. Physical chemistry c. Life support systems organic or inorganic tests d. Metallurgical analysis 3. Support analysis of experiment data in above areas and, as required, in geochemistry analysis.	Specialties (as required) a. Biochemistry b. Geochemistry c. Physical Chemistry d. Organic/Inorganic e. Chemical Engineering Academic Background Bachelors degree in chemistry with work in one or more of the above specialties. Other Experience: 5 or more years experience in above area(s).	Special Courses FPE Experiment Requirements a. Objectives b. Set-up, Checkout operators and data collection c. Refurbishment d. Job and analysis equipment Special Experience: Team training on FPE's supported	150-175 40-50	Hard mockups or prototype FPE and laboratory equipment.	Subsystems FPE's LS-1, LS-6	Station design Station experiment program ECLSS user orientation Shirtsleeve performance

Table 6-31. Crew Training Requirements for Metallurgist, Skill Type 23

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Task 1. Prepare set-up and checkout equipment and specimens for experiments 2. Conduct/supervise/monitor experimental operations 3. Collect data, process test specimens and evaluate quality test procedures 4. Discuss results with PI's on ground and modify experimental operations as required Secondary Tasks 1. Deactivate/terminate experiments 2. Package test specimens and experimental/support equipment for return to ground	Specialty: Physical metallurgy Academic Background: PhD in physical metallurgy; major course work in physical metallurgy, metallurgical thermodynamics, theory of metals/metallic micro-structure, kinetics, diffusional phenomena in metals, plastic deformation and fracture. Other Experience: 8-10 years experience as research metallurgist. Broad range of materials and processes desirable	Special Training Courses 1. FPE/Experiment a. Objective b. Set-up and experimental operations. c. Specimen evaluation d. Ground support capability Special Briefing Principal investigator briefings Other Special Experience Team training exercises, with Electromechanical Technician assigned to same FPE	100-150 50-75 20-30	Mockups Metallurgical laboratory facilities None Part-task trainers	FPE: MS-1 T-4	Station design Station experiment program ECLSS user orientation Shirtsleeve performance

Table 6-32. Crew Training Requirements for Materials Scientist, Skill Type 24

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks 1. Schedules, prepares, performs and evaluates experiments in manufacturing and research activities in space. 2. Results and products will be evaluated and communicated to Earth. Secondary Tasks 1. Terminate experiment operations.	Specialty: Materials Scientist Academic Background: PhD in physics, major work in physics of solids and fluids, and fundamentals of metallic and nonmetallic materials. Other Experience: 4-5 years' experience as research scientist with study in crystal growth, glass processing, isolation and measurement of basic fluid properties.	Special Training Courses 1. FPE/Experiment a. Objectives b. Design and characteristics c. System set up and data collection d. Product evaluation and preparation e. Ground support capability Special Briefings Principal Investigator briefings	100-150 50-60	MS/MS Mockup part-task trainers	FPE MS-1	Station design Station experiment program ISS user orientation ECLSS user orientation Shirtsleeve performance

Table 6-33. Crew Training Requirements for Physical Chemist, Skill Type 25

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks 1. Prepare experiment and set-up equipment. 2. Perform laboratory support tasks, as required in: a. Physical chemistry b. Life support systems organic or inorganic tests c. Metallurgical analysis 3. Support analysis of experiment data in above areas.	Specialties: (as required) a. Physical Chemistry b. Organic/Inorganic c. Chemical Engineering Academic Background: Masters degree in chemistry with major course work in one or more of the above specialties. Other Experience: 5 or more years experience in the above area(s).	Special Courses FPE Experiment Requirements a. Objectives b. Set-up, Checkout operators and data collection c. Refurbishment d. Job and analysis equipment Special Experience: Team training on FPE's supported	150-175 40-50	Hard mockups or prototype FPE and laboratory equipment	Subsystems ECLSS FPE's 1-4	Station design Station experiment program ECLSS user orientation Shirtsleeve performance

Table 6-34. Crew Training Requirements for Agronomist, Skill Type 26

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
<u>Primary Tasks</u>	<u>Specialty</u>	<u>Special Training Courses</u>				
1. Prepare, set-up and checkout experimental/support equipment	Agronomist	1. Earth Surveys Overview	50-75	Visual aids graphics illustrating sensor data potentials	ES-1	Station design
2. Plan, integrate, and conduct/supervise daily experimental operations	<u>Academic Background</u>	a. Introduction to meteorology, oceanography, geology/geodosy				Station experiment program
3. Screen, edit, correlate, enhance, and analyze data return	Ph. D. in Engineering (sensors/optics), agricultural sciences with extensive training in sensors, optics and data processing.	b. Earth Surveys sensor design/operations				Station personnel
4. Compile and format data for ground and discuss with PI's	<u>Other Experience</u>	c. Sensor data evaluation/signature analysis				ISS user orientation
<u>Secondary Tasks</u>	8-10 years' experience in field, including aerial or space (global) observation methods and analyses	d. ERTS mission/accomplishments				ECLSS user orientation
1. Deactivate/terminate experimental operations		2. FPE/Experiments	100-150	Module mockup. Station/module interface monitor/control simulator		Shirtsleeve performance
		a. Objectives				
		b. Module design				
		c. System set-up and data collection				
		d. Ground support capability				
		e. Module/subsystem maintenance				
		<u>Special Briefings</u>				
		Principal investigator briefings	75-100	None		
		<u>Other Special Experience</u>				
		Team training exercises with FPE	20-30	Module mockup Station module interface simulator		

Table 6-35. Crew Training Requirements for Geographer, Skill Type 27

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks	Specialty	Special Training Courses				
1. Operate sensing equipment and observe performance	Geographer	1. FPE/Experiments	100-150	Module mockup of Earth Observation Facility	FPE	Station design
	Academic Background	a. Objectives			ES-1	Station experiment program
2. Perform quick-look data evaluation to check quality and proper sensor operation	PhD in geology, Meteorology, or Engineering (sensors, optics)	b. Set-up and experiment operations				ISS user orientation
	Other Experience	c. Ground support capability				ECLSS user orientation
						Shirtsleeve performance
3. Perform data evaluation, discrimination, and transmittal to ground	5-8 years experience with research in geology, agriculture, or hydrology.	Special Briefings				
		Principal investigator briefings	50-75	None		
Secondary Tasks		Other Special Experience				
Perform shutdown operations		1. Team training exercises with scientists	15-20	Mockup		
		2. Use of remote sensing instruments aboard aircraft.	15-20	Instrumented high altitude aircraft (C-135, B-52, etc.)		

Table 6-36. Crew Training Requirements for Spacecraft Commander, Skill Type 28

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks 1. Provide authoritative control of Space Station. 2. Assume responsibility for safety of all crewmen and integrity of Space Station systems and equipment. 3. Provide administration and management of station, its operations, resources, and personnel. Secondary Tasks 1. Perform direct flight control and/or Systems Management operation-maintenance 2. Support experiment activities	Specialty: space operations Academic Background: Systems engineering degree or electrical engineering with systems emphasis or aeronautical engineering with systems emphasis. Post-graduate courses in flight control/dynamics, orbital mechanics, and spacecraft systems highly desirable Other Experience: Systems test experience as pilot or engineer. Previous Space Station mission highly desirable	Special Training Courses			Subsystems All FPE's All	Station experiment program overview Shuttle design overview Pressure suit performance
		1. Station module flight control a. Station stabilization and control b. Module navigation, guidance and stabilization control c. Station/module berthing interfaces	225-250 (approximately 150-175 hours on simulator)	Module flight simulator		
		2. Orbital Mechanics/Flight Dynamics Theoretical refresher course with extensions to station, experiment module, and shuttle applications	120-150	None		
		3. Station/Module subsystem operation and management	225-250 (approximately 50-75 hours on simulator)			
		4. Experiment Designs a. General functions b. General structure/subsystem design c. General operations and emergency procedures. d. Specific design and operations features	50-75 for basic course	Full-scale mockup		
		Special Briefings				
		1. Station commander duties	10-20	None		
		2. Team training exercises with experiment crewmen under PI's direction	40-50	Module flight simulator		
		3. Ground launch and module tracking facilities	20-30	None		
		Other Special Experiences				
		1. Team training exercises for each FPE assigned to support.	30	Module flight simulator		
		2. Team training exercises with other flight operations and maintenance personnel.	100			

Table 6-37. Crew Training Requirements for Flight Controller, Skill Type 29

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
Primary Tasks 1. Perform station flight control (guidance, navigation, and control) 2. Assist flight control (terminal rendezvous) and berthing of shuttle and all modules. Secondary Tasks 1. Assist or direct corrective maintenance of all station experiment electronics equipment and systems. 2. Support or conduct engineering FPE's	Specialty: Flight Control and dynamics. Academic Background: Electrical engineering with systems emphasis. Post-graduate courses in flight control/dynamics, orbital mechanics, and spacecraft systems highly desirable Other Experience: Systems test experience as pilot or engineer highly desirable	Special Training Courses 1. Station module flight control. a. Station stabilization and control b. Module navigation, guidance and stabilization control c. Station/module berthing interfaces.	225-250 (approximately 150-175 hours on simulator)	Module Flight Simulator	Subsystems ISS G&C EPS FPE's C/N-1 and all electronics	Station experiment program overview Station personnel Shuttle design overview ECLSS user orientation Pressure suit performance
		2. OrbitalMechanics/ Flight Dynamics Theoretical refresher course with extensions to Station, experiment module, and shuttle applications	120-150	None		
		3. Experiment module design a. General module functions b. General module structure/ subsystem design c. General module operations and emergency procedures. d. Specific module design and operations features	50-75 for basic course plus 35-50 for unique control requirements	Full-scale mockup		
		Special Briefings 1. Station commander and systems engineer capabilities and duties	10-20	None		
		2. Team training exercises with experiment crewmen under PI's direction	40-50	Same simulators used for special training courses, No. 1 above.		
		3. Ground launch and module tracking facilities	20-30	None		
		Other Special Experiences 1. Team training exercises for each FPE assigned to support	50	Same simulators used for special training courses, No. 1, above		
		2. Team training exercises with other flight operations and maintenance personnel	100			

Table 6-38. Crew Training Requirements for System Engineer, Skill Type 30

Tasks Required	Specialty and General Background	Special Training Required	Special Training Duration (hours)	Special Training Aids Equipment and Facilities	Elements Supported	General Training Required
<u>Primary Tasks</u>	<u>Specialty</u> Flight control and dynamics.	<u>Special Training Courses</u>			<u>Subsystems</u>	
1. Perform station electromechanical subsystem operations and management.	<u>Academic Background</u>:	1. Station module systems control.	225-250 (approximately 150-175 hours on simulator)	Module flight simulator MSV	RCS FPS FC/LSS Structures	Station experiment program overview Station personnel
2. Monitor basic subsystem support parameters.	Systems engineering degree or aeronautical engineering with systems emphasis. Post-graduate courses in spacecraft systems highly desirable.	a. Station system management b. Module electromechanical subsystems			<u>FPE's</u> All with electromechanical equipment	Shuttle design overview ISS user orientation Pressure suit performance
<u>Secondary Tasks</u>	<u>Other Experience</u>:	c. Station/module interfaces				
1. Direct or assist in corrective maintenance of all station and experiment electromechanical equipment and systems.	Systems test experience as pilot or engineer highly desirable.	2. Experimental design a. General functions	50-75 for basic course plus 35-50 for each unique module being studied	Full-scale mockup		
2. Support or conduct engineering FPE's.		b. General structure/subsystem design c. General operations and emergency procedures d. Specific design and operations features				
		<u>Special Briefings</u>				
		1. Station commander/navigator capabilities and duties	10-20	None		
		2. Team training exercises with experiment crewmen under PI's direction	40-50	Same simulators used for special training courses, No., above.		
		3. Ground launch and module tracking facilities	20-30	None		
		<u>Other Special Experiences</u>				
		1. Team training exercises for each FPE assigned to support	40	Same simulators used for special training courses, No. 1, above		
		2. Team training exercises with other flight operations and maintenance personnel.	100			

Training Personnel Estimate

To maintain a historical record and assist in defining the scope of training for other programs, the Apollo training group has maintained statistics from early in the Apollo program through the current period. Some of these statistics are presented in Table 6-39 in cumulative form for the 96-month period. The statistics from Apollo were used to prepare space station subsystem training estimates for a 48-month period, considering the relative Apollo and space station subsystem complexity and differences in operation. The difference in time period is due to the fact that peak activity for Apollo occurred during a 4-year period on a classic bell curve, versus the full 96-month period for Apollo statistics, which are cumulative as presented. These statistics and estimates are for all NASA and contractor personnel on contractor subsystems courses, but do not include FPE training. The actual period of training support for the space station by the contractor may start as early as the preliminary design review and last until the fourth or fifth station crew is briefed. This support builds slowly to a peak before space station launch and tapers off in the period of the fifth crew briefing, contractor capability being maintained to support NASA presentation of the courses after that period.

Personnel training statistics for Apollo indicate that approximately an equal number of NASA and contractor personnel were trained; this ratio is projected for the modular space station.

6.4.4 TRAINING EQUIPMENT

A cursory description of the functional types of training equipment required to support the general training identified in Tables 6-4 through 6-8 is given in the following paragraphs.

Station Crews

The use of computer-simulated systems integrated with the flight-type information subsystem is required for conducting simulated vehicle flight operations. Capability is required to accomplish and/or develop normal crew procedures, malfunction analysis, and manual overrides through the use of special training tapes and the ISS. The ultimate objectives are to duplicate anticipated spacecraft performance with computer-simulated systems and to demonstrate the adequacy of the integrated system design and man/machine interfaces by way of control and display consoles to fulfill the modular space station missions.

Mockup provisions should include high fidelity representation of a partial core module power boom and two station modules. The station

Table 6-39. Training Estimates

Item	Apollo Statistic (8 years)	Space Station (Estimate 4 years)
Number of subsystems	11	7 or 10
Average number of students per class	20	15
Average hours per class	13	15
Average students per month	300	300*
Number of classes (total)	1,958	1,200
Total student hours (NASA and contractor) for subsystems training	369,787	216,000**

*Based on ten systems presented two times per month and 15 hours per class.
**Based on 300 student-hours per month for 48 months.

modules selected for the training mockup are (1) the crew/control module (SM-1), which houses the control console, data analysis and photo laboratory, and (2) the laboratory module (SM-2), which incorporates the mechanical, optical, and earth surveys laboratory. Functional simulation of selected subsystem assemblies will be required to include part-task equipment for operator-maintenance crew activities, e.g., ECLSS components, EPS interfaces, ISS software changes, alignment and use of G&C assemblies, and structures interface connections. The capability to demonstrate station housekeeping provisions, station habitability, and emergency procedures will be required. Functional simulation of the earth-surveys laboratory equipment is required for training of experiment crew personnel in all aspects of experiment planning, prepass, and postpass activities.

A partial mockup of the interior of an experiment module is required. Mockup detail may be of low fidelity and should provide a typical configuration in which critical crew tasks (e.g., installation or removal of massive items) may be rehearsed and component access problems may be resolved. This training device is to be designed for use in an underwater environment.

Capability to provide environment acclimation training for station crew members is required. Capability is needed to acquaint crew members with the sensation of weightlessness. Crew member introduction to the zero-g environment may be provided through Keplerian trajectory aircraft flights, underwater simulation of zero g, or both. Working instruments used in the underwater simulator include a pressure garment assembly (PGA) test stand, pressure garment consoles, three-man ventilation and pressurization console, and a bioinstrumentation console. Requirements for part-task equipment for operator-maintenance crew activities include partial mockups of ECLSS components, RCS interfaces, structures interfaces, cargo doors, and cargo handling equipment.

Required training equipment support items include graphic displays and various training aids. Crew training includes a general space flight preparation, familiarization with procedures used in transit to and from the station via shuttle, and training in survival methods for emergency earth landing of the shuttle in remote uncivilized areas.

Mission Management

Training equipment requirements for mission management personnel will be influenced by the complexity of the mission management function and the nature of training required. In most cases, actual hardware is expected to be used in conjunction with the existing training site facilities to provide mission management and mission support training. The mission management facility may contain a mission control center similar to that of the Apollo program, but considerably reduced in scope because of the autonomy of the on-board checkout and navigation functions. Accommodations may be provided for experiment and operations planning conferences and support operations for the mission management facility. The mission support facility provides the primary functions of acquisition, tracking, and communications for command and control, and the secondary functions of data processing, timing, and displays and control at each site for quick-look data analysis and uplink processing.

Crew Support

Training equipment requirements for the crew support personnel category may, in general, be satisfied through existing facilities, i.e., mission support vehicle, simulation equipment, and training classrooms. Scheduling of these facilities is to be on a noninterference basis with station crew training. Unique or additional training equipment is not required.

Design, Test, and Quality Assurance

As with the crew support element, training equipment requirements for this personnel category can generally be satisfied with the existing crew training site facilities. No unique requirements have been identified.

Administrative

Equipment required for administrative personnel is normally limited to classroom facilities with supporting training aids and documentation.

6.4.5 SPACE STATION CREW TEST PARTICIPATION

Crew participation, especially by the flight operations crew, in subsystem and total integrated design and testing of hardware provides a high confidence level in the program for the crew members involved. It is of particular benefit to training if such participation is planned.

Briefing sessions prior to major design program or mission milestones are effective in increasing crew awareness of design approaches, mission requirements, and the program in overview. This increased awareness benefits the crew and contractor in the decision-making process when crew preference for a design or mission element is under consideration.

Crew Involvement

Generally, the MSS flight crew involvement in acceptance and delivery site test and checkout activities is determined by time available and is restricted to critical test and checkout procedures that demand their participation. This familiarization training is the final phase of crew training before the actual mission flight, and will permit the crew to function in a vehicle representing as close as possible the actual vehicle. The CAV or MSV may be used for familiarization training when available. The flight crew should monitor integrated systems tests and monitor, or have the option to participate in, tests and checkout of the initial MSS or modules during the period from module facility compatibility tests at the assembly and launch sites through the prelaunch countdown checkout. Support technicians and scientific personnel participate to a lesser extent.

The spacecraft commander assigns flight crew members or their backup members to monitor or participate in testing and checkout of a depth required to instill crew confidence in the tests and overall MSS operation.

Sufficient space and facilities in the assembly and launch site area should be made available to accommodate certain assembly specialists required for on-orbit assembly, activation, and checkout of the module cluster. Special crews consisting of at least two members will be utilized on orbit to establish and verify interface connections between the shuttle and station, subsystems activation and checkout, and preparation of the MSS for quiescent (unmanned) operations. Typical module assembly operations and checkout are estimated to require approximately five days. The broad range of complex activities to be accomplished in this relatively short period will require extensive and comprehensive cross training of the two-man crew. Pressure-suit qualification also will be required.

6.5 TRAINING SYSTEM

Figure 6-3 is a basic flow diagram defining the approach to MSS module contractor crew training. Key inputs and interfaces are shown and major tasks are defined. Primary output products are identified and some of the intermediate products and tasks are included to provide flow diagram continuity. The flow diagram generally follows the system engineering approach.

The solid-outline blocks in Figure 6-3 are defined in detail in this section of the document. Inputs or interface functions which are not part of the direct training planning process, but which are related to this process, are presented in dashed outline blocks. These related blocks are discussed briefly in the following paragraphs to clarify the planning process and provide continuity.

The functions, products, and interfaces shown on the illustration in dashed boxes include man-machine trade studies to determine mission requirements and core module equipment design, and the preparation of mission functions and flight operations flow diagrams that provide inputs to training planning. The test plans and training plan define the recommended station crew participation and the systems briefings required to support crew participation in test activities.

The Maintenance and Logistics Support Plan (Section 7) and attendant mission-support requirements analysis provides station crew and mission management personnel requirements for maintenance, maintainability, level of maintenance, etc. These outputs are refined by each iteration of the analysis as the program develops and are used to develop maintenance training requirements.

Training equipment specifications, schedules for training hardware and graphics, and final training equipment design must be selected to meet training equipment recommendations by appropriate man-machine-cost tradeoffs.

Flight crew procedures, maintenance manuals, and specific training documentation, as well as manuals for operation and maintenance of simulators, serve as general training documentation.

Complete station crew and NASA mission support personnel training is a NASA responsibility; contractor participation is provided at the mission-operation system and subsystem briefing level. The solid- and dashed-line portions of this block in Figure 6-3 indicate this dual responsibility.

Descriptions of the solid-outline blocks on the flow diagram (designated by number) are given in the following paragraphs:

1. Station Crew Personnel and Training Equipment Requirements. This task consists of the preparation of training requirements and their logical grouping on the basis of mission timelines, skill data, system definition, and design-to data. The product of this effort is used to define the training courses, equipment, and graphic aids needed to meet station operational and maintenance objectives set forth in higher level documentation. For each machine function involving a manual task, a training requirement must be analyzed.

2. Mission Support Personnel and Training Equipment Requirements. Under this task training requirements are prepared and allocated on the basis of support requirements analysis and review of subsystem operation and maintenance. The grouped requirements are used to define the training courses, equipment, and graphic aids recommended to meet program and station support objectives. Each man-machine interface requires analysis for training impact.

3. (Station Crew) and 4 (Mission Support) Personnel Planning Information. These blocks are shown for flow continuity. The tasks consist of a detailed review of NASA requirements documentation and meetings with NASA. This review is used to modify training requirements and confirm them with contractor training management and NASA. Man-machine trade studies are reviewed to assist in making decisions on training and training equipment for maximum effectiveness. The basic concept for training and training equipment is developed for review with management and NASA and to obtain NASA guidance in preparing the training plan. In addition, the initial inputs to the test plan and to the launch site operations plan for crew participation are provided. The iterative process of review and refinement is performed as applicable at this point in the flow in order to pick up data or requirements for feedback from analysis and products farther along in the flow.

5. Training Equipment Recommendations. This product is a summary of station crew and mission support personnel functional requirements and recommended equipment. Station crew maintenance repair capability, graphics, and all equipment schedules for

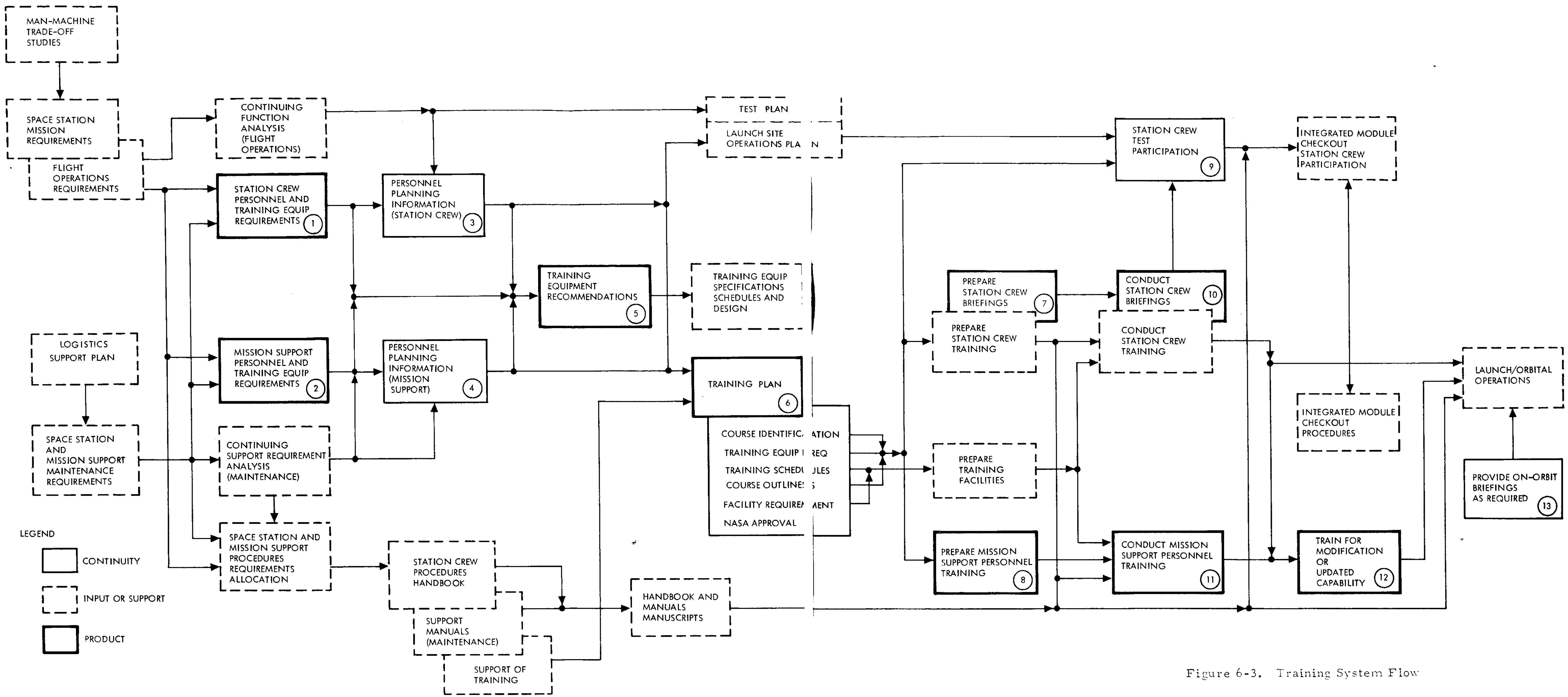


Figure 6-3. Training System Flow

for training support are described. A requirement summary is prepared at the personnel task level by types of personnel for final detailed allocation of training equipment, and preliminary scheduled need dates for training equipment are established. Detailed descriptions and drawings or sketches are prepared to define the equipment recommended. These descriptions and allocations of equipment are reviewed by management and NASA for guidance in the preparation of training equipment specifications. The schedules are used for program planning, preparation of training equipment, and development of the training plan.

6. Training Plan. The training plan presents the space station and mission management personnel training program and is the final detailed Phase C and D planning output. It begins with enumeration of tasks for which training is required, and describes the scope and depth of training to meet the requirements. As the program progresses, informal plans are developed for crew training exercises, simulators, and part-task trainers. All data related to training planning and plan preparation are gathered, and a detailed outline and dummy layout of the plan are prepared for management approval. During the iterative process, personnel planning information serves as a basis for plan development. A preliminary plan is reviewed with management and NASA for concurrence or direction. The final plan is completed subsequent to mission and subsystems design; contractor management and NASA approval is obtained and the plan is implemented.

7. Preparation for Station Crew Briefings. The product consists of prepared final detailed space station crew briefings, instructor lesson materials, and rough illustrations for graphic aids. Briefing graphics and narrative system descriptions for handout materials are prepared. The depth of the narrative system descriptions depends on the availability of station crew handbooks. Operational data, drawings, schematics, and system specifications are researched, and meetings are held with design personnel to develop the briefing material. Outlines established in the training plan are used as a baseline to prepare detailed instructor lesson materials for the briefings, which are repetitive. The materials are continually updated as the program changes to ensure that each crew is briefed from the latest data. All data must be coordinated and collated for final presentation.

8. Preparation for Mission Management Personnel Training. This product consists of preparing the final detailed mission management personnel training courses, beginning with the outlines in the training plan. Instructor lesson materials and rough illustrations

for graphic aids are also produced. The task is the same as that required for the station crew however, greater variation occurs in the depth of presentation because of the greater diversity of personnel types in this category. In general, this category is composed of all the engineering and technical management personnel at the contractor and NASA facilities, the launch crew, mission management, and members of the scientific community.

An additional requirement is involved in the completion of tasks for Blocks 7 and 8. Detailed system functional operations, and maintenance and repair documentation must be available to support Space Station crew and mission management personnel training; otherwise, the instructor must prepare interim training documentation.

9. Flight Crew Test Participation. This function is not formal classroom training; however, the flight crew can be involved in acceptance testing. Although this participation is on a crew-optional basis, it must be planned in the training plan, and test plan. The periods of participation are preceded with crew briefings to provide up-to-date information and increase crew involvement.

10. Conduct Station Crew Briefings. Indoctrination or detailed briefings are conducted at contractor and the NASA facilities before design reviews, FPE acceptance, Station system acceptance, test participation, or checkout. Subject matter varies in scope and depth, depending on the crew, subject, amount of crew involvement and the group being addressed; i.e., flight crew, support technicians or experiments personnel. These technical briefings, however, are specifically tailored for the Station crew. The task includes traveling as required to conduct both formal or informal briefings and coordination of the briefing, materials, scheduling, and facilities.

11. Conduct Mission Personnel Training. Classes are conducted at the contractor or NASA facilities on program, Station, FPE's, system and subsystems functions, and maintenance tasks for contractor and NASA engineering, launch, mission management and scientific community personnel. Training course materials, scheduling, and facilities are coordinated, and travel is performed as required to conduct formal training. Operational and maintenance-oriented training should involve the related equipment when possible.

12. Training for Modification or Updated Capability. Briefings or courses are given as required to update all personnel on new or additional space station and mission management capability and equipment modification.

The task consists of analyzing change documentation to prepare delta briefings and courses for station and mission management personnel and providing these presentations either directly or through the on-orbit station and ground CCTV. Station equipment modifications installed in the mission support vehicle (MSV) for form, fit, and function should be reviewed by the on-orbit crew through direct and taped CCTV for training purposes.

13. On-Orbit Briefings. Briefings for on-orbit station crew members are supplied as required through the use of CCTV or program instruction. FPE instructions, procedure changes, and upgrading are communicated via on-orbit briefings.

6.6 TRAINING COURSES

6.6.1 COURSE-CONTROL DOCUMENTATION

The purpose of course-control documentation is to support each formal training activity, enable NASA personnel responsible for the administration of station training to evaluate the scope of coverage available from a contractor, establish a common reference point on the level of training for each course, and provide visibility to NASA organizations on the detail of contractor training available.

6.6.2 STATION TRAINING

Classroom training on the space station subsystems consists of courses on subsystems in the nominal configurations, augmented with delta (updating) courses as required for each successive crew and for groups of other personnel. Updating courses usually are presented at Level 2 (for crews, they are given at Level 3) and do not include refresher training, except when required to clarify changed information.

6.6.3 COURSE-CONTROL DOCUMENT DEVELOPMENT

Training levels are described in Paragraph 2.4. The precise definition of Levels 1, 2, and 3 for specific NASA personnel groups is accomplished by selection of topics from nominal Level 1, 2 and 3 training-course descriptions and outlines, which are baseline course definitions. These levels are modified to meet the specific personnel group. During Phase C, course descriptions and outlines are not prepared for update courses since they are extensions of Level 2 courses and are based on configuration changes that cannot be predetermined.

Table 6-40 shows the format for a typical list of contractor training courses. At this time, the list is not complete, and course levels and lengths are not considered to be accurate. The table is shown merely as a sample of Phase C and D training plan products.

The course description is a narrative of the course. The course outline, as shown in Paragraph 2.7, defines the course content with an estimate of the classroom time intended for each major division of the outline. The course outline and the course descriptions provide identifying features associated with these courses that closely relate them to NASA requirements.

Table 6-40. Modular Space Station Training Systems Courses

Nominal Level	Course Number	Course Title	Course Length (hours)
1	SXXX	Station Briefing	24
2	SXXX	Electrical Power Subsystem Familiarization	12
3	SXXX	Electrical Power Subsystem Course	18
2	SXXX	Reaction Control Subsystem Familiarization	10
3	SXXX	Reaction Control Subsystem Course	18
2	SXXX	Structures Subsystem Familiarization	18
3	SXXX	Structures Subsystem Course	30
2	SXXX	Environmental Control and Life Support Subsystem Familiarization	12
3	SXXX	Environmental Control and Life Support Subsystem Course	22
2	SXXX	Crew and Habitability Subsystem Familiarization	10
3	SXXX	Crew and Habitability Subsystem Course	18
2	SXXX	Information Subsystem Familiarization	26
3	SXXX	Information Subsystem Course	35
2	SXXX	Guidance and Control Subsystem Familiarization	20
3	SXXX	Guidance and Control Subsystem Course	30

This relationship is shown in the sample course description for the electrical power subsystem (EPS). The feature is that each course has two variations from the basic presentation, one with a subsystem management emphasis and one with a subsystem equipment emphasis. In general, emphasis of specific items implies slightly more detail, greater stress on the subject matter, and more questions to the class to assure that the particular portion is understood.

The Level 2 and 3 presentations on subsystems are emphasized as follows:

1. Subsystem Equipment Courses (E). Emphasis is on the physical configuration of the equipment, including its functional and physical interfaces with other equipment.

2. Subsystem Management Courses (M). Emphasis is on the operational use of the equipment, including functional operations and the typical procedures associated with these operations.

The course descriptions and the EPS course outline are shown only to indicate the depth of content and the format; Phase C requirements allocations are required to delineate appropriate subjects, times, emphasis, etc.

Two course descriptions are presented on the following pages. The first defines a Level 1 program and space station overview briefing; it is a format without the emphasis just described. The second description covers a Level 2 subsystem familiarization and provides the format with the emphasis included. Level 3 course descriptions resemble the Level 2 descriptions, except for greater depth and scope in the "AREA" and "EMPHASIS" columns.

COURSE DESCRIPTION

Course Title	Modular Space Station Subsystems Briefing
Course Number	SXXX
Course Length	24 hours (22 hours off-site)
Security Classification	Unclassified
Student Load	Minimum: 10 Maximum: 25

Course Objective

This course familiarizes the student with the Space Station. The course includes an overall description of the program and describes the Station, missions, and Station subsystems.

Course Scope

The presentation begins with an overall description of the program, including program objectives, milestones, and contractor participation. A general description of the Station systems, hardware, configuration, and utilization is presented next. This description is followed by a description of a mission, during which the systems capabilities and requirements as well as the experiments are discussed. The remainder of the course is devoted to a discussion of the subsystems of the Station. The structures subsystems are discussed first. This discussion includes a description of the Station axes and the general specifications, structure design, and deck layout and utilization.

The guidance and control subsystem is the subject of the next discussion. It includes the G&N components, functional control loops, and modes of operation. This portion is followed by a discussion of the attitude control that encompasses the RCS components, requirements, and operation. A presentation on the information subsystem is next; it includes the requirements for, and operation of, the equipment as it is related to the control and monitoring of other subsystems. A discussion of power generation and distribution requirements is included in the EPS presentation which follows.

The next presentation is on the environmental control and life support subsystem. The operation and management of the subsystem for the CO_2, water, and waste-management components are discussed. A description of a typical crew compartment, crew equipment utilized is provided during the crew and habitability subsystems presentation.

Location of Training

Contractor's facility; MSC, Houston; KSC.

Method of Presentation

Lecture (60 percent) and conference (40 percent).

Recommended For

This course is recommended for personnel new to the program who require an overall familiarization with the Station, the Station subsystems, and their interfaces. Applicable areas are as follows:

1. Mission Management
2. Crew Support
3. Design and Test
4. Reliability and Quality Assurance, and Quality Control

Course Prerequisites

None

Configuration Applicability

This is a program-oriented course and, therefore, reflects the initial Station prior to launch.

COURSE DESCRIPTION

Course Title — Modular Space Station Electrical Power Subsystem Familiarization

Course Number — SXXX

Course Length — 12 hours

Security Classification — Unclassified

Student Load — Minimum: 5
Maximum: 20

Course Objective

This course provides the student with a basic knowledge of the electrical power subsystem. There are two variations to this course that result as a requirement of subsystem management or equipment emphasis based on student knowledge requirements. Depending upon the emphasis required, this course will provide student knowledge in the following areas:

Area	Emphasis: Equipment	Emphasis: System Management
The student will have a basic understanding of the relationship between the electrical power subsystem, the Station crew, and the Station.		*
The student will be able to identify the physical characteristics of the main components in the electrical power subsystem.	*	
The student will be able to identify the functional flow associated with primary solar panel operation and backup fuel-cell operation.	*	
The student will be able to identify the electrical buses and to discuss the functional purpose of each.	*	
The student will be able to identify monitoring and backup operation for the electrical power subsystem and to understand the function of each.		*

Course Scope

The course presentation begins with an explanation of the electrical power subsystem requirements for the Modular Station and the interfaces required with other Station subsystems. The major functions (d-c power, a-c power, displays) and their interface are presented next. Generation of d-c power is discussed next and includes a description of the solar panels, and regenerative fuel cells. This description is followed by a discussion of d-c power distribution, including bus identification and data flow. Generation and distribution of a-c power is discussed next and includes a functional and physical description of the inverters, bus systems, and inverter control circuits. The EPS controls and displays on the consoles completes the course.

Location of Training

Contractor facility; MSC, Houston; KSC.

Method of Presentation

Conference (100 percent) if no trainer is used. If a trainer is used, the method of presentation is conference (80 percent) and demonstration with the trainer (20 percent).

Recommended For

This course is recommended for personnel in the following areas:

Area	Emphasis	
	Equipment	System Management
Crew Support. Supervise the design development and operation of the Station training equipment involving the electrical power subsystem. Supervise preparation of the operations handbook involving the electrical power subsystem.		*
Mission Management. Establish flight control of the electrical power subsystem. Furnish electrical power subsystem requirements and support to the mission control center and the necessary interface with networks. Prepare flight plans and power profiles. Assess the EPS periodically on request.		*
Test and Evaluation. Develop electrical power subsystem simulation for the purpose of evaluating and testing of EPS hardware. Monitor EPS integration with other spacecraft systems.	*	
Reliability, Safety, Quality Assurance, and Quality Control. Monitor and inspect the EPS during final assembly and acceptance testing. Prepare reliability and safety criteria and monitor tests.	*	

Course Prerequisites

Completion of Space Station Briefing Course SXXX or equivalent knowledge is a prerequisite.

Configuration Applicability

This is a basic subsystem course and reflects a nominal station configuration.

6.7 TRAINING COURSE OUTLINES

The training course outline is used as a control document by NASA and the contractor to provide training course visibility to administrators and potential students.

The format is the same for all levels of training. The sample provided in this section of the plan is for a Level 2 course presentation. Each of the courses prepared, such as those listed in Table 7-1, requires a course outline for a Phase C training plan.

Both the course outline in this section and the course description in Paragraph 6.0 concern Space Station Electrical Power Subsystem Familiarization. They are so presented to show the relationship between the contents of a course outline and a course description.

SXXX
Course Outline

Course Title: Space Station Electrical Power Subsystem Familiarization
Course Number: SXXX
Course Length: 16 hours
Hours per Day: 4 hours
Security Classification: Unclassified
Student Load: Minimum: 5
Maximum: 20

Unit	Outline	Time	Training Aids, Material, and Trainer	Emphasis: Equipment	Emphasis: Systems Management
I	Introduction	01:00	EPS training handout material will be used throughout the course.		*
	A. Electrical power requirements				
	1. Peak power 2. Power conservation				
	B. Components providing power		Transparencies		
	1. Solar array panels 2. Regenerative fuel cells				
II	Subsystem Description	00:30			
	A. Subsystem components		Transparencies	*	
	B. Component locations and accessibility		Transparencies	*	

SXXX
Course Outlinet

Unit	Outline	Time	Training Aids, Material, and Trainer	Emphasis: Equipment	Emphasis: Systems Management
III	D-C Power Generation	05:00			
	A. Solar array panels		Transparencies	*	
	1. Solar array orientation mechanism				
	B. Fuel cells				
	1. Regenerative fuel cell system (flow diagram)				
	2. Energy storage				
IV	D-C Power conditioning and distribution	01:30			
	A. Bus system and components powered		Transparencies	*	
	1. Primary and secondary				
	2. Power distribution schematic				
	B. Safety circuits		Transparencies	*	

SXXX
Course Outline

Unit	Outline	Time	Training Aids, Material, and Trainer	Emphasis: Equipment	Emphasis: Systems Management
V	A-C Power Generation	02:00			
	A. Inverters		Transparencies		
	1. Description 2. Requirements 3. Operation (block diagram) 4. Internal control circuits a. Voltage and current regulation b. Overload sensing				
	B. Inverter control circuits		Transparencies		
VI	A-C Power Distribution	01:30			
	A. Bus system and components powered		Transparencies		
	1. A-C busses 1, 2, 3, and 4 2. Power distribution schematic				
	B. Safety circuits		Transparencies		
VII	EPS Controls and Displays	01:30			
	A. Controls, displays, and indicators		Transparencies		*
	1. Control centers				
	B. Malfunctions and isolation		Transparencies		*

SXXX
Course Outline

Unit	Outline	Time	Training Aids, Materials, and Trainer	Emphasis	
				Equipment	Systems Management
VIII	EPS Mission Phase Configuration	00:30			
	A. Phase configurations		Transparencies		*
	B. Peak-power operations		Transparencies		*
	C. Emergency power operations		Transparencies		*
IX	Mission Management Interface	00:30	Transparencies		
	A. Parameters to ISS				
	1. Solar-cell 2. D-C distribution subsystem 3. A-C distribution subsystem 4. Controls condition				
X	EPS Distribution to Systems	01:30	Transparencies		
	1. EPS 2. ECS 3. G&N 4. RCS 5. ISS 6. FPE's (attached)				

6.8 TRAINING EQUIPMENT

During the Phase C process of correlating specific training tasks with specific types of training equipment, a design-to training equipment performance requirement is prepared by the process described in Paragraph 5.0. The required performance characteristics are allocated to specific equipment, and narratives and sketches are prepared to describe the equipment. These data provide a planning base for NASA and serve as a basis for design, training, cost trade decisions by NASA. They also provide the training basis for design groups to preparation of training equipment specifications.

Detailed need dates and lead-times for training equipment are established in Phase C.

Follow-up of the requirements specified by training planning and human engineering functions assures that equipment meets the training needs and that the trade selections represent the best approach to meet the training need.

Training equipment software and hardware update is relatively automatic. The flight systems software and hardware, and training equipment flight systems software and hardware, will be the same, having been verified in simulators prior to implementation on the MSS.

6.9 CREW TRAINING FACILITIES

Crew training sites and crew-related facilities are required to support the activities defined in the Phase C crew training plan. The training sites are a part of the overall mission operations support systems.

Crew training sites must provide facilities dedicated to general preparation, indoctrination, and procedural practice for space station crewmen. These sites also must provide for required training of all ground personnel.

The estimated 300-hour-per-month presentation time (Table 6-39) requires that six classrooms be provided, each assumed to be in use approximately 60 hours per month for classes and 60 hours per month for instructor preparation, dry runs, and critiques. The 120 hours per month per classroom is based on a 6-hour-per-day, 20-day-per-month utilization. Three of the six classrooms should be located at the contractor's facility; the others may be located at NASA sites. Additional classrooms are required at FPE contractor's facilities. All of these classroom requirements are considered to be available at most contractor sites and NASA sites and do not necessarily represent a new requirement.

The training equipment considerations (Paragraph 8), when defined in Phase C, will be used to size the facilities in conjunction with results of the Phase C analysis of training class sizes.

6.10 MANAGEMENT REQUIREMENTS

6.10.1 MANAGEMENT SYSTEMS

Points related to contractor purview appear in the plan where appropriate. In addition, Paragraph 5.0, Training System, provides the contractor's approach to a total system for a training program.

A training management system cannot be fully described at this time, since it is difficult to project NASA and contractor policies and organization for training in the mid-Phase C and Phase D periods.

A number of recommendations and guidelines for NASA are presented in this section relating to existing policies or for contract imposition on a Phases C and D contractor. These guidelines are designed to ensure the management and operation of a training system that provides the most cost-effective training program.

6.10.2 RECOMMENDATIONS AND GUIDELINES

1. Since training simulation and contractor engineering simulation (either full or part-task) on the space station mockup and the on-orbit systems and operations are generally similar, if not identical, it is imperative that software mechanization and development be effort for all of these vehicles. All simulators and other modules or vehicles, therefore, will use the same software as the on-orbit vehicle.

   The objective is to move toward a single software development and verification program for the initial MSS and simulators with faster and more accurate verification when design changes to the on-orbit vehicle affecting software are directed by NASA and subsequently checked on the simulators and CAV or MSV.

   Space station simulators and part-task training devices developed for dynamic station operating practice may require special software control and interface routines, processors, etc. These routines will provide special effects and initialization of the trainers for different modes of operation, such as initializing to a predetermined mission point or system function, and halting for data collection or consulation. The subsystem software simulating onboard station operation will be the same as actual software used on the station. Other simulator and training devices already in the NASA and contractor inventory and applicable to station training will not be subject to this concept. An example is the NASA-MSC docking simulator.

2. In the interests of securing commonality of data, cost avoidance, and efficiency of operation, contractor support functions must be under single management. These functions stem from operational concepts, design requirements, reliability factors, human factors, and other criteria which are developed into a common baseline and allocated to training, training equipment design, engineering simulation design, support documentation, and test and checkout conduct. Consideration must be given to technical adequacy and economically sound functional time phasing of these functions. This requirement can be accomplished by placing these functions physically adjacent to each other and relating their statements of work to each other to provide maximum interface effectiveness.

   A single requirements analysis for all these functions can provide the baseline for each separate product; however, individual functions research is required so that for each function the knowledge and skill is provided to produce separate products, since the products do diverge from a common set of requirements. Cost avoidance is possible by common use of support documentation graphics and subsystem descriptions for training, training equipment design, checkout activities, and station operation and maintenance. A support change control can be established for these functions to ensure single notification of hardware and software modification resulting from engineering change. This activity can serve to ensure updating of training equipment when station form or function changes. Common pools of similar data, drawings, specifications, etc., may also be maintained by a central source for all these functions.

   The objective is to provide a common technical multidisciplined group of support personnel whose tasks, functions, and products stem from closely related man-machine requirements and at the same time, to reduce the flow of traffic usually required of individuals and groups interfacing in these functions for normal and change operations.

3. The concept for the MSS training program should include NASA controls for all training through the use of training control coordinators or managers. These personnel would interface

with contractor and scientific community counterparts. As a minimum, coordinators should be considered for the space station crew, mission management, shuttle, the contractors, and the scientific community. These personnel would act as single-point contacts and should be assigned early in the Phase C planning period for training planning and training priority determination.

4. Control of the conduct of contractor training can be accomplished by NASA's requiring the contractor to prepare the upcoming month's schedule and a 3-month estimate of classes. In addition, reports showing classroom hours, instructor hours, and training classes completed are considered a requirement. To effect this operation in real-time, the contractor and the NASA hold identical training schedules for all personnel categories. The coordinators mentioned in Item 3 can identify the need for specific classes to the contractor as planned, modified, or for open periods. The dual schedules are modified in real time by the coordinator and contractor (within contractor manning limits), and the contractor responds to the new schedule.

5. Training personnel must be involved in the system engineering process early in Phase C to define mission and system training requirements and develop recommendations on training equipment and graphics. A capability must be developed early in Phase C to provide flight crew briefings for PDR, CDR, and major mission development and design milestones so that the Astronaut Office or candidate flight crew can participate with the latest available data.

7. MAINTENANCE AND LOGISTICS SUPPORT

7.1 PURPOSE

This section defines the requirements for the establishment of a maintenance and logistics support system to conduct effective operation of the modular space station throughout its life cycle.

7.2 SCOPE

A maintenance and logistics program for the design, development, and operational phases of the modular space station and the requirements, tasks, interfaces, and documentation necessary to implement the maintenance and logistics program are described and include:

Support Requirements Analysis - to determine maintenance requirements; spares, consumables, and material requirements; skills; special equipment and tools; and other support resources.

Maintainability Analysis - to define design characteristics necessary to preserve or restore an element of the MSS to an operational state with minimal expenditure of resources.

Supply Support - to identify the hardware resources, schedules, and techniques needed to provide maintenance and other support capabilities for the MSS program.

Technical Support Documentation - to provide descriptive and procedural data pertaining to ground and mission maintenance and operation of equipment.

Test and Operational Support - to define the requirements for repair and modification control, storage and deployment of spares, consumables, GSE, and other support resources and services.

7.3 MAINTENANCE AND LOGISTICS SUPPORT CONCEPT

The success of the modular space station depends upon effective logistic support throughout the programmed life cycle. These support requirements must be identified and integrated with design, development, production, and operational requirements to assure program success. Integration of logistics and maintainability requirements is achieved through the iterative system engineering process (Figure 7-1). This process will provide an effective combination of design and support criteria for final design. In addition, the individual logistic functional elements will be integrated with each other and with the other elements of ground operations to achieve a cost-effective balance of all elements. This integration with the ground operations elements of manufacturing, test, training, facilities, ground support equipment and launch operations will be accomplished through the Common Data Base (CDB). The determination of logistics requirements will be aided by inputs to the CDB from mission operations, engineering, and other systems analysis as depicted in Figure 7-2. Support requirements will be derived from the CDB and a feedback prepared to provide a basis for further analyses. The test and operational data will be utilized to confirm and revise requirements in subsequent phases of the program.

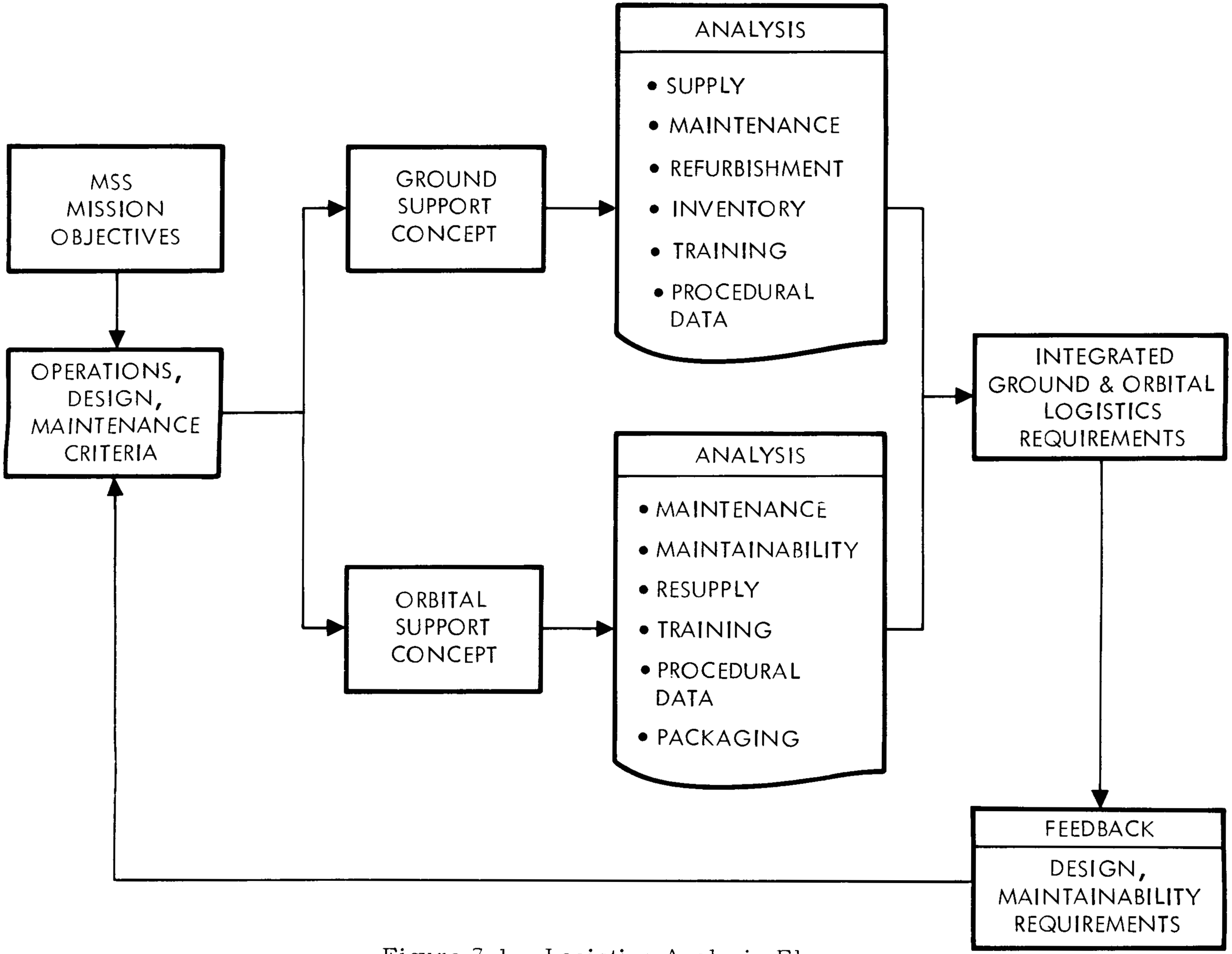


Figure 7-1. Logistics Analysis Flow

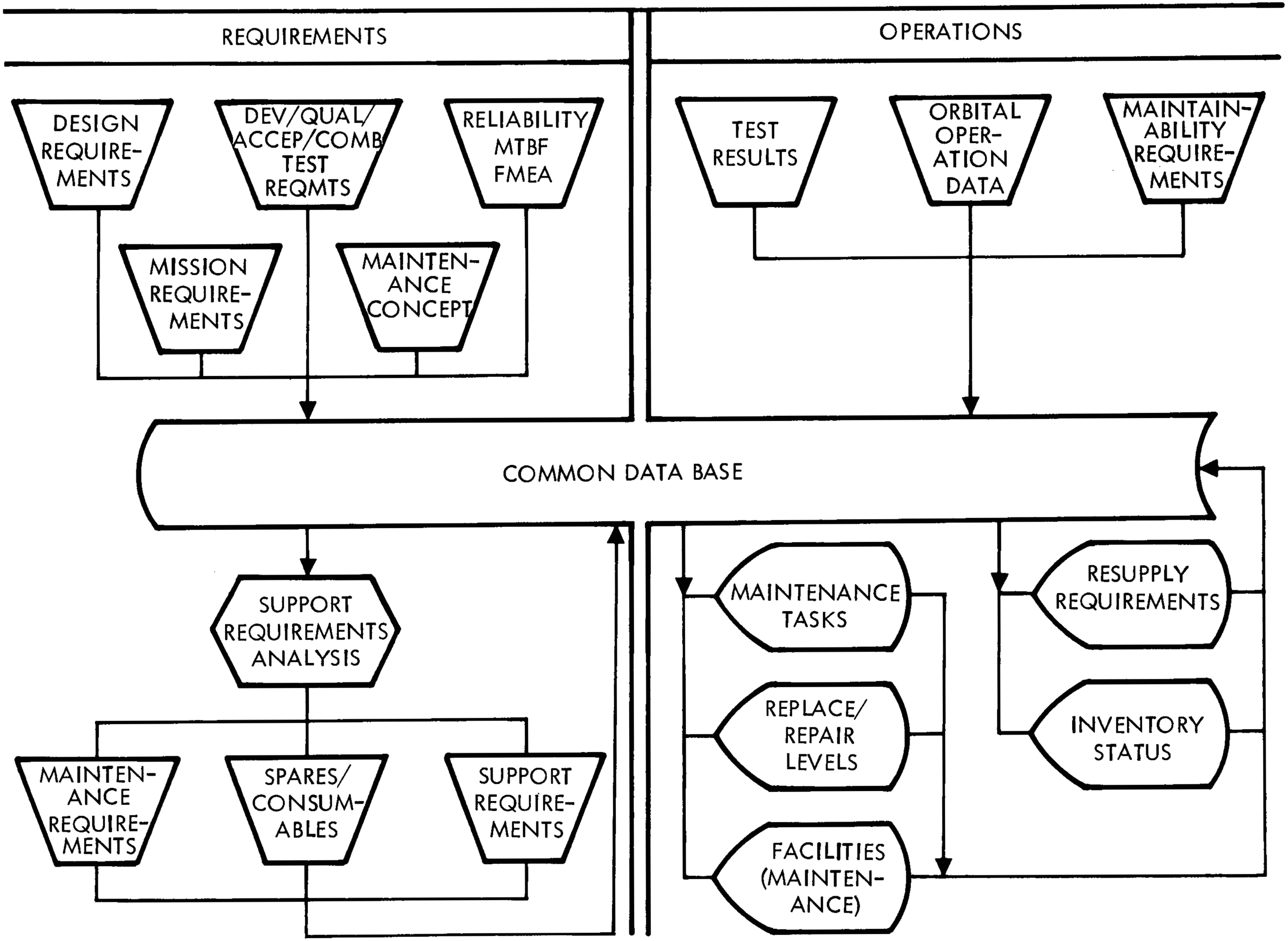


Figure 7-2. Logistics Data/Common Data Base Interface

7.4 REQUIREMENTS

7.4.1 SUPPORT REQUIREMENTS ANALYSIS (SRA)

The identification of support requirements and resources is established on the basis of preliminary operational, maintenance, and design concepts. Each of these concepts is derived from the operational objectives of the MSS which generate the basic total system criteria and requirements. The operational requirements will be used to develop support and maintenance analyses to a lower level of requirements. The support requirements analysis will provide early and effective identification of resource requirements. The support requirements analysis is the primary integrating function in the maintenance and logistics system.

7.4.2 MAINTAINABILITY

The extended missions of the MSS intensify the need for maintenance in space. Maintainability considerations will be included in the development of all designs, including ground support equipment and spares. A maintainability analysis program will be established to aid in describing the design characteristics of the subsystems and equipment that require maintenance. Maximum utilization will be made of existing documentation to define maintainability design guidelines. These guidelines will generate specific MSS design criteria ranging from design practice groundrules to mandatory design requirements included in end item and procurement specifications.

7.4.3 SUPPLY SUPPORT

A supply support and spares system will be developed to support the test and operational phases of the MSS program. The supply support and spares program will assure availability of support resources required for test, maintenance, and operational activities.

Quantitative requirements will be defined in concert with the maintenance concept, and initial and resupply requirements will be considered. A controlled material acquisition system will be established for the fabrication or procurement of spares, consumables, and other technical operating supplies. A warehousing system will be established for spares, GSE, mortality parts, and other technical operating supplies throughout the life of the program.

An inventory data management system will be implemented to provide consumption data and assist in determining the content of each resupply launch. The system will be programmed to produce reports that provide visibility of physical inventories, stock balance and consumption data, and inventory reviews.

7.4.4 TECHNICAL SUPPORT DOCUMENTATION

Support documentation will be provided to furnish the descriptive and procedural data necessary for ground and MSS flight hardware maintenance and operation. The data developed will be applicable for crew training, ground equipment maintenance, and MSS maintenance. Existing data will be used to effect savings within technical and program constraints.

7.4.5 TEST SUPPORT

Logistics support during the development and test phase is a function that will be provided to assure timely, economic, and effective accomplishment of that phase. Test requirements and planning will be integrated with the logistics system development. The logistics system will, in effect, provide the services to the test organization normally provide during an operational phase and provide for an orderly transition to the operational phase. These services will meet the applicable testing requirements and will consist of elements of the following functions:

Supply support and spares
Maintenance and repair control
Warehousing
Equipment control and scheduling

7.4.6 OPERATIONS SUPPORT

Requirements for the establishment of operations support services will be developed from experience gained in the test support phase. Maintenance and usage data obtained during the test program will be used to update the support resources planning, including spares levels, support equipment, and repair services. The basic operations to be performed in support of operations are summarized as follows:

Accumulate, control, and distribute hardware and software required for resupply, repair, modification, and maintenance of MSS and support equipment

Process and control hardware for repair, modification, and maintenance

Control and coordinate handling equipment, tooling, and support equipment utilization.

7.5 IMPLEMENTATION AND MANAGEMENT

7.5.1 SUPPORT REQUIREMENTS ANALYSIS

Approach

The objective of this analysis is to identify the resources required to accomplish the logistics functions of the program and to organize and integrate these requirements into a usable document. In previous programs the timing of the efforts and lack of integration allowed various groups to begin their own requirements analysis simultaneously. Supply performed an analysis to determine spares, maintenance engineering performed an analysis to determine maintenance requirements, and both the logistics and GSE design groups performed analyses to determine GSE requirements. Consequently, the basic analyses were redundant. There are areas of support that are the specific responsibility of certain logistics disciplines. For example, spares quantities, allocation, etc., are the specific responsibility of the supply group. However, the criteria and background for these specific determinations come from common areas. The common data base (CDB) will provide the initial factor for determining the support requirements and resource for the program. One of the initial inputs to the CDB will be the maintenance concept or policy. Emphasis will be on accomplishing maintenance at the lowest level practical and on establishing self-sufficiency of the MSS regarding maintenance. Because of the importance of the maintenance concept to other functional elements, it is explained in the following paragraphs.

The maintenance concept is based on operational requirements of the MSS. The extended missions require that inflight maintenance be performed to sustain the functional integrity of the subsystem. The capability of returning maintenance-significant items to earth allows for items to be replaced inflight and the MSS to be resupplied with spares. Therefore MSS maintenance is separated into two major categories; inflight and ground. These categories will be further developed and specific maintenance requirements identified as design progresses. There will be occasions when items will require maintenance that was not scheduled, such as random failure and accidental damage. Therefore, inflight maintenance is further categorized as scheduled and unscheduled, and including the functions of removal, replacement, adjustment, inspection, servicing, testing, etc. Ground-based maintenance performed on those items returned from the MSS include these functions and repair, overhaul, and modification.

Process Description

A maintenance-support engineering analysis process will be established. This analysis will be conducted concurrently with the design process and will identify and describe the following:

The required maintenance tasks, their sequence and location

The spares, consumables, and other materials required to perform the tasks

The type and quantity of personnel required to perform the tasks

The support documentation required

The maintenance facilities for tasks performed on returned items

Both mechanized and manual systems are available to NR to perform this analysis. It is anticipated that the system incorporated will be an optimum balance between machine and manual operations to assure effective and efficient use of the analyst's time, yet avoid unproductive machine use.

To develop this analysis and the necessary documentation, the activity sequence will be implemented for guidance of assigned personnel:

Gain a general knowledge of the MSS program objectives

Gain a thorough knowledge of the subsystems and equipment

Prepare a functional description of the subsystem

Develop functional flow charts for maintenance

Develop and document tradeoffs in connection with subsystem maintainability and maintenance design

The assigned logistics and maintenance personnel will maintain liaison with other personnel within the total ground operations functions and with design engineering as the analysis progresses. This will preclude redundant analysis and unnecessary contacts with the design engineer.

Format for the support requirements analysis will take full advantage of existing programs and procedures for similar functions. The primary concern, however, is to ensure that the format is compatible with that established for inputting to the CDB.

7.5.2 MAINTAINABILITY ANALYSIS

Approach

The objective of the MSS maintainability analysis is to assure that the design and installation of subsystems and components can be maintained within the constraints of crew and subsystem operations. Subsystem units have been analyzed to estimate the following factors concerning the replaceable units:

Criticality of function
Operating life
Replacement complexity
Maintenance requirements
Safety

On the basis of the above, the replaceable units (ground and inflight) were further analyzed to determine those that require information subsystem support (fault detection and fault isolation).

Preliminary results indicate that 2,509 of the 3,299 inflight replaceable units (IFRU) and 665 of the 756 ground replaceable units (GRU) require information subsystem (ISS) support. The utilization of the ISS to monitor the status of selected parameters will minimize maintenance demands by sensing degradation so action can be taken to prevent failures, but not prematurely which would cause unnecessary expenditure of resources. During Phase C, maintainability analysis of the MSS vehicle and equipment will be conducted to develop the design aspects necessary to perform maintenance within the prescribed constraints. Evaluation of the various designs will be conducted as a continuous effort throughout the design phase.

Design Requirements

Design criteria will be expanded and amplified to include maintainability design requirements. These will be stated both in general terms, as applicable to the subsystem, and in specific terms, as applicable to individual components. Maintainability design constraints will be in consonance with, and provide support to, the established maintenance concepts and requirements. The maintainability design requirements include such characteristics as accessibility, serviceability, repairability, adjustability, and related operations with the objective of influencing design toward reducing:

The complexity of maintenance tasks
The need for scheduled maintenance
Maintenance downtime

The potential for maintenance error
Post-maintenance checkout

Design Evaluation

Modular space station drawings, specifications, and design data will be reviewed to ensure consideration of maintainability. A maintainability design review checklist will be used during M analysis and by the design groups. An analysis report will also be used to document maintainability problems, investigations, recommendations, and resolutions identified during the course of the analysis. Engineering will review the M analysis report to expedite resolutions prior to final design approval. Examples of the checklist and report are shown in Figures 7-3 and 7-4.

Verification

Maintainability verification will be integrated with manufacturing, test, and operational activities to determine problems early and minimize verification costs. This process will verify that maintenance and support requirements derived through analysis are valid and have been satisfied. Specifically, the maintenance criteria developed during design will be compared to the actual requirements generated in the integrated tests. Malfunctions, failures, and other unsatisfactory conditions will be corrected using the data and resources predicted in the analysis. Data will be collected for each occurrence; adjustments to the maintenance requirements and procedures and design changes may result from this verification. Design changes are expected to be minimal due to prior analyses.

7.5.3 SUPPLY SUPPORT

Approach

Forecasting of spares requirements and costs will begin early in the design phase. This will provide the maximum degree of support at optimum cost. Spares will be negotiated concurrently with production requirements to obtain best price per unit.

Delivery of spares will be scheduled to reduce funding requirements during the early portion of the program when costs in other areas are at a high level.

The approach for developing initial spares requirements is summarized as follows:

Spares candidates will be identified through the support requirements analysis and Common Data Base outputs.

Project/Task:

Document No: Rev.: Date: (+)

Part No: Analyst:

FACTOR	N/A	SAT	COND	UNSAT
Accessibility				
1. Openings, panels & doors	( )	( )	( )	( )
2. Covers, plates & caps	( )	( )	( )	( )
3. Drawers, frames & slides	( )	( )	( )	( )
4. Internal work space/volume	( )	( )	( )	( )
5. Internal lighting, paint	( )	( )	( )	( )
6. Location, arrangement	( )	( )	( )	( )
7. Other	( )	( )	( )	( )
Other Maintainability Features				
8. Test & service points	( )	( )	( )	( )
9. Cases, shields & guides	( )	( )	( )	( )
10. Interlocks, overrides & stops	( )	( )	( )	( )
11. Lines, cables & connectors	( )	( )	( )	( )
12. Disconnects, latches, catches	( )	( )	( )	( )
13. Fasteners, pins, safety wirings	( )	( )	( )	( )
14. Mounting & packaging	( )	( )	( )	( )
15. Controls & displays	( )	( )	( )	( )
16. Coding, labeling & pathways	( )	( )	( )	( )
17. Parts, assemblies, modules	( )	( )	( )	( )
18. Fuses, circuit breakers	( )	( )	( )	( )
19. Other	( )	( )	( )	( )
Time Utilization				
42. Readiness & preparation time	( )	( )	( )	( )
43. Active maintenance downtime	( )	( )	( )	( )
44. Administrative lag	( )	( )	( )	( )
45. Supply time	( )	( )	( )	( )
46. Waiting time	( )	( )	( )	( )
47. Parts availability	( )	( )	( )	( )
48. Other	( )	( )	( )	( )
Work Space				
56. Emergency egress	( )	( )	( )	( )
57. Space for men & equipment	( )	( )	( )	( )
58. Walking & visual link space	( )	( )	( )	( )
59. Efficiency of layout	( )	( )	( )	( )
60. Shelves, drawers, hangers	( )	( )	( )	( )
61. Other	( )	( )	( )	( )

(+)N/A - Not Applicable
SAT - Satisfactory
COND - Conditional
UNSAT - Unsatisfactory

Figure 7-3. Maintainability Factor Checklist

MPAR NO.:	1	DATE:	2	DEADLINE DATE:	3
DOC. NO.:	4	REV:	5	DATE:	6
SITE:	7			RESP DESIGN ENGR:	8
SUBSYSTEM:	9			INTERFACE REQMTS:	10
EQUIPMENT:	11				

STATEMENT OF PROBLEM: 12

INVESTIGATION: 13

RECOMMENDATIONS: 14

RESOLUTION: 15

ORIGINATOR: 16 DATE CLOSED: 17

1. MPAR NO. - IDENTIFICATION NUMBER OF MPAR - MAINTAINABILITY FUNCTION MAINTAINS LOG CONTAINING NUMBERS, DATE ASSIGNED, DEADLINE DATE, AND ORIGINATOR.
2. DATE - DATE MPAR NUMBER IS ASSIGNED.
3. DEADLINE DATE - DATE ACTION TO BE TAKEN MUST BE COMPLETED.
4. DOC NO. - NUMBER OF DRAWING OR OTHER ENGINEERING DOCUMENT WHERE MAINTAINABILITY PROBLEM WAS IDENTIFIED.
5. REV. - REVISION LETTER OF DOCUMENT.
6. DATE - DATE OF DOCUMENT.
7. SITE - SITE OR SITES AFFECTED.
8. RESP DESIGNER - RESPONSIBLE ENGINEER, DEPT/GRP & TELEPHONE.
9. SUBSYSTEM - SUBSYSTEM AFFECTED.
10. INTERFACE REQMTS - INTERFACES AFFECTED.
11. EQUIPMENT - SPECIFIC EQUIPMENT AFFECTED.
12. STATEMENT OF PROBLEM - THE PROBLEM SHALL BE DESCRIBED IN SUFFICIENT DETAIL TO ENSURE THE COOPERATION OF THOSE INVOLVED IN ITS RESOLUTION. ALL BACKUP INFORMATION SUCH AS SKETCHES, PRINTS, AND OTHER REFERENCE MATERIAL SHALL BE ATTACHED OR REFERENCED. NO PARTICULAR FORMAT REQUIREMENTS ARE PLACED ON THE BACKUP MATERIAL OTHER THAN THAT THEY BE LEGIBLE, UNDERSTANDABLE, AND CLEARLY RELATED TO CONTENT OF THE MPAR.
13. INVESTIGATION - DATE REGARDING THE EFFECTS ON THE OPERATION OR MAINTENANCE TIME, COST, EFFORT OR ERROR SHALL BE PROVIDED. ESTIMATES OF THE PROBABLE EFFECTS OF ALTERNATIVE RECOMMENDATIONS SHALL BE DEVELOPED AS REQUIRED. NEGATIVE ACTION RECOMMENDATIONS SHALL BE RECORDED AND SUPPORTED, AND ESTIMATES OF THE TIME, EFFORT, AND COST REQUIRED TO IMPLEMENT RECOMMENDATIONS WILL BE INCLUDED TO PROVIDE A SOUND BASIS FOR DECISIONS.
14. RECOMMENDATIONS - ALTERNATIVE RECOMMENDATIONS SHALL BE LISTED IN ORDER OF PREFERENCE. EACH SHALL BE JUSTIFIED IN TERMS OF ITS EFFECTS ON THE SUBJECT EQUIPMENT, SYSTEM PERFORMANCE, MISSION OBJECTIVES, AND MAINTAINABILITY CRITERIA AND PRINCIPLES.
15. RESOLUTION - (ACTION TAKEN OR TO BE TAKEN SHALL BE IDENTIFIED WHEN THE ALTERNATIVE RECOMMENDATIONS HAVE BEEN COORDINATED AND DECISIONS HAVE BEEN MADE. DOCUMENTATION OF COMPLETION SHALL BE REFERENCED OR ATTACHED WHEN AVAILABLE).

17. DATE CLOSED - DATE MPAR IS CLOSED.

16. ORIGINATOR - MPAR ORIGINATOR.

Figure 7-4. Maintainability Problem Area Report

Quantity will be determined by optimizing cost versus support risk

Mission-critical spares will be identified

Bulk hardware will be selected

Resupply requirements and controls will be optimized for best overall program support

The acquisition and management system for the MSS inventory will provide for phased delivery, repair, modification, or overhaul, control, and visibility of inventory activities throughout all phases of the program.

Requirements Development

Each replaceable unit will be considered a spares candidate. This will provide a baseline for additional analysis of operational environment, maintenance frequency, utilization, quantity, repairability and procurement factors. The computation of the optimum spares quantity to be provisioned can be determined by several methods. One method, using a spares optimization model, computes the best tradeoff, for a given risk factor, between cost of additional spares versus the cost of system downtime due to an unsupported failure. A mechanical computation formula considers factors such as usage, failure rate, lead time, support period, and turnaround time. These and other procedures for prediction are complex and require detailed inputs which are generally not available during Phase B. Regardless of the process utilized, the initial list of recommended spares and support material will be compiled from the requirements analysis and supplemented by the Common Data Base. The recommended spares will be subjected to the concurrence and approval of representatives from Engineering, Material Manufacturing, Quality, and Test.

Initial Spares

The planning for initial spares will be based on the Common Data Base outputs, such as operational requirements, equipment utilization rates, onboard storage location, operating life, operating time, failure rates, repairability and related items critical to safety and mission accomplishment. The initial support requirements will include the critical bits and pieces used for all levels of component repair.

Resupply Spares

Resupply requirements will be based upon predicted and subsequently actual usage of equipment, consumables, and technical operating supplies necessary to operate and maintain the MSS and ground support operations. MSS consumption data will be transmitted to the ground-based inventory management system to assist in determining the content of each resupply launch. Adjustment to stock levels will be made if required. Similar inventory interfaces will be established for central management control of all program inventories.

Acquisition and Control

A controlled material acquisition system will be provided for fabrication or procurement of spares, GSE, consumables, modification kits, and other operating supplies that are authorized through provisioning procedures. This system will have controls to preclude duplicate procurement, to provide effective control and management of provisioned hardware, mortality parts, and other critical items, and to provide rapid on-line inventory status pertaining to total support requirements and inventory activities. The system will interface with the CDB and the on-board data management subsystem.

7.5.4 TECHNICAL SUPPORT DOCUMENTATION

Documentation Description

The initial documentation developed for this program will consist of existing engineering data and illustrations to meet the requirements.

The documentation will be inputted to the CDB to provide descriptive and procedural data for the maintenance and operation of ground and flight equipment. The depth of coverage will be consistent with the maintenance levels identified.

The typical printed manual format will not be applicable to the MSS program for all maintenance and operation data applications. The presentation media for ground equipment will not be the most effective or economical for use by the MSS crew in orbit. The level of detailed requirements by the crew will permit the use of simplified task-oriented procedural data for scheduled maintenance. The format will be thoroughly investigated for cost savings potential, adaptability to fast reaction changes, and adaptability to CDB computerized readouts. Subcontractors and suppliers authorized to prepare support documents will be required to conform to the prime contractor's specifications.

Procedures will be validated by personnel during test, training, mock-up development, and in actual use on the equipment for which they were developed.

7.5.5 TEST SUPPORT

This function includes the quantification of test support equipment (spares and GSE) based on expected usage and repair capabilities at the using location; the acquisition of test support equipment; and the management of the inventory assets to assure availability of equipment.

Supply Support and Spares

The supply support function will accumulate the hardware and software to support specific tests. Provisions will be made to inspect, store, and issue the items required for a test. Processing of hardware returned by the test organization for maintenance, repair, or modification will be accomplished.

Maintenance and Repair Control

This function will provide complete control of affected hardware through each step in the maintenance and repair cycle to ensure adherence to costs and schedules. The maintenance and repair effort will be coordinated with production and material to assure the most effective and economic accomplishment. The use and development of in-house repair capabilities will be encouraged to preclude potential problems in the operational phase of the program.

Warehousing

A warehousing system will be implemented to support the testing operations. If necessary, satellite warehouses will be established at off-site testing locations. Test hardware, operating supplies, and test support equipment will be controlled. The functions of the warehouse will include receiving, storage, locator system, and shipping or issue.

Equipment Control and Scheduling

The equipment concerned here is that used for (a) test article systems control, (b) measurement of test article systems performance and (c), equipment used for other related functions such as special handling, maintenance, calibration, communication, data transmission, and servicing. Test planning requirements will be coordinated with the test engineer-conductor to assure that all prerequisites for support equipment and supplies will be available at the test location.

7.5.6 OPERATIONAL SUPPORT

Site Activation

Activation will encompass the installation and verification of equipment applicable to the operational cycle of the MSS Program. Included will be the general planning, scheduling, receipt, assembly, installation, test, and integration of equipment to verify interfaces and performance and assure compatibility of the facility, support equipment, and the MSS.

Support Services

The intent of the support services function is to provide an orderly transition from the test period to the operational phase. The functions will generally be non-technical in nature such as shipping, transportation, facilities purchasing, and coordination with the customer and contractor on support matters.

Support to Operations

The functions developed for support during the test phase will be expanded to include the operational requirements. The prime objective is to assure that facilities, hardware, personnel, and data are made available at the proper time and in the proper quantities.

The elements to accomplish operational support will include the following:

Supply Support and Spares - material procurement, storage, distribution, and planning for mission support operations. Specific emphasis on preparing resupply kits for the MSS and maintaining adequate stock balances through a mechanized inventory management system.

Maintenance and Repair Control - Support will be provided for maintenance, repair, modification, and refurbishment functions to assure that schedules are met and cost constraints observed. Existing contractor, supplier, or NASA facilities will be utilized for this activity to the maximum extent practical, rather than developing new facilities and capabilities. It is anticipated that approximately 80 percent of this activity can be accomplished at the operational site.

8. LAUNCH SITE OPERATIONS

A study of the launch site operations was conducted to determine the requirements of the launch site. The study was conducted with a minimum cost approach and maximum use of existing facilities and GSE as a goal.

8.1 LAUNCH SITE TEST CONCEPT

The basic concept for the module checkout consists of comprehensive factory testing of each module and of the assembled space station modules comprising one operational volume (the first four modules) prior to shipment of any flight module to the launch site. Prelaunch checkout will normally consist of minimal post-shipment system verification checks and interface verification before loading the modules into the orbiter cargo bay. Modules returned from orbit for refurbishment, repair, or modification would require more comprehensive system validation than the initial prelaunch verification. Preparation of modules SM 3 and SM 4 for launch, as well as the growth station modules, will include individual and combined systems tests and acceptance tests.

Consideration was given to many factors in addition to those directly related to the launch of the MSS elements.

The MSS concept extends the launching and support operations over a period of several years and consequently will change the roles of the manufacturing and launch sites from those generally accepted in present and past programs. Ordinarily, the production period has exceeded or been coincident with the completion of the test operations. In these cases, the manufacturer normally provided engineering and logistics support throughout the test and operational program. This mode of operation will not be likely during the shuttle era because many of the contractors and vendors in the project will no longer be involved after launch of the initial station. Consequently, responsibility for the supporting functions now performed by the manufacturer will have to be assumed by the launch site or some other facility. Typical functions considered to be in this category are as follows:

1. Support engineering and documentation control

2. Spares procurement, maintenance, and storage

3. Software development, maintenance, and control

4. Refurbishment of MSS and experiment modules

5. Acceptance testing

   a. Last three initial station modules

   b. Growth station modules

   c. Cargo modules

   d. Experiment modules from vendors

   e. Refurbished modules

   f. Recycled modules

   g. IFRU's and GRU's

   h. Software

   i. Modifications

6. Maintenance and operation of laboratory-type equipment for component checkout, repair, and calibration

7. Data reduction and test analysis

8. Evaluation of anomalies in support of the orbiting station.

An integration tool will be required at the development and the acceptance and delivery sites for the development of subsystems and the integrated checkout of the initial MSS. Use of a similar device is the most desirable approach to support the majority of the functions listed above.

An examination of the requirements and schedules indicate that the sharing of this equipment between manufacturing and the launch sites is feasible. This equipment will initially be used as a compatibility assessment vehicle (CAV) for acceptance testing of the initial station modules, and is designated a mission support vehicle (MSV) when installed at the launch site. It will be transferred to the field site in accordance with the schedule shown in Section 2 and be available for acceptance checkout of the last three station modules and provide an operational tool for evaluation of contingencies or changes that may occur during the buildup or subsequent operations.

Historically, the trend has been to minimize prelaunch testing at the launch site for various reasons. The program goal (for the initial modular space station) has been to completely prepare the module for launch at the acceptance and delivery site, and thereby reduce the field site operations to those required to service and launch the module. The concepts of minimal checkout requirements and high reliability must be attained if an airline type of operation by the shuttle is to become a reality. Because the design and development of the initial MSS is scheduled to lag behind the shuttle by approximately four years, the feasibility of these test concepts and operational procedures will have been demonstrated by the time the MSS is sent to the launch site.

Factors that have been considered in determining the prelaunch and launch operational requirements for the growth MSS elements are as follows:

1. Many of the modules will have been in storage before being prepared for launch.

2. Although many of the modules will be similar, no two will be identical. This results in different checkout and operational requirements for each module and increases the probability of late engineering changes requiring rework and system reverification.

3. Safety requirements may necessitate draining the module subsystems of fluids (such as Freon). This will result in subsystem servicing and validation requirements at the launch site prior to launch.

4. System revalidation, resulting from engineering changes, faulty components, changeout of life-limited hardware, and software will be required.

As a result of these considerations, it has been determined that the capability for integrated checkout (MSV) should be at the launch site for support of the program after the initial four module acceptance at the acceptance and delivery site. The extent of the checkout for each individual module will be determined from its subsystem configuration, the time period it has been in storage, data trends, modifications, etc.

The integrated and operational testing will be divided into two phases. The first phase will cover the time period during which the initial six-man station is developed and launched, and the second phase will cover the remainder of the operations at the launch site.

8.1.1 INITIAL STATION MODULE PHASE

Acceptance testing of MSS, experiment, or refurbished modules will be accomplished at the acceptance and delivery site.

Those modules required to accomplish the basic functions of the initial MSS (PM, CM, SM-1, and SM-2) will have been installed and checked out in the flight module checkout vehicle. The modules will then be shipped to the launch site by air transport in as near a launch-ready condition as practical, but in an inactive mode.

The UTE will be the primary mode of checkout at the launch site. The flight modules will be subjected only to system verification type tests with the UTE because the initial station modules previously will have operated in an integrated station at the factory.

Because the shuttle flights dedicated to the launching of the MSS program elements represents such a small percentage of the total shuttle missions, interfaces and requirements for checkout (utilizing shuttle equipment) will be minimized, particularly in view of the short turnaround requirements, airline-type operational concept, and the number of agencies that may be involved. The problems associated with coordinating and effecting changes for a dedicated flight in a timely manner will require careful planning. Measurements to be monitored by the shuttle data system also will be minimized for the same reasons.

Checkout and servicing will be accomplished primarily in three areas: a receiving and checkout facility similar to the MSOB or low bay, a shuttle checkout and integration facility, and a launch pad.

Representative functions are as follows:

1. Receive and offload module from Guppy-type aircraft
2. Receiving inspection and configuration verification
3. System verification tests
4. Install in orbiter cargo bay
5. Servicing and shuttle/payload interface checks
6. Move to pad
7. Service time-critical elements and launch

8.1.2 POST-INITIAL STATION MODULE PHASE (INCLUDES GROWTH STATION MODULES)

After transfer of the integration tool to the launch site, many of the associated functions will be transferred to this site because the factory will be phasing out production of station modules. In this study, it is planned that the launch site will assume responsibility for the integrated testing of SM-3, SM-4, cargo module, and the growth station elements, verification of procedural modifications, design changes, configuration verification, etc. Also to be included is the responsibility for programming changes and software modifications.

Acceptance testing of the final three modules for the initial station and the growth MSS program elements will be accomplished at the launch site. Similarly, experiments requiring integrated testing will be sent directly to the launch site.

Maintenance and refurbishment of modules returned from orbit will be accomplished at the launch site.

Prelaunch and launch operations will be accomplished as described in the section.

8.2 MSS FLOW PLAN AT THE LAUNCH SITE

Figure 8-1 represents the prelaunch and launch operations master plan from the facility preparation through the mission operations with the initial station. This includes GSE installation and checkout, initial station modules preparation and launch, MSV buildup, and cargo modules preparation and launch. It supports the MSS project master schedule (refer to MSS Program Master Plan, SD 71-225).

Figure 8-2 represents a typical flow path for modules. The modules arrive at the launch site at the shuttle runway, either delivered from the factory or returned from orbit. When returned from orbit, they are removed from the orbiter in the VAB and transported to the MSOB for servicing. Cargo is loaded into the cargo modules in the warehouse and weight and balance operations are accomplished in the MSOB. The modules are installed in the orbiter in the VAB, then the shuttle is transferred to the pad for launch operations.

The MSS modules delivered from the factory will arrive at KSC by air (Guppy). The longitudinal (X-axis) of the modules will be in a horizontal position all during shipment and transport to the MSOB.

The modules will be moved to the MSOB for utilizing the module transporter.

8.2.1 MSOB RECEIVING INSPECTION (INITIAL AND GROWTH MODULES)

Receiving inspection will consist of a visual inspection of all interface details using standard inspection aids.

The berthing port interface checkout stand, in conjunction with peripheral ground support equipment and UTE, will then be used for an electrical interface verification test to determine gross status of the module. This test will include standard checks such as continuity, resistance, polarity, and will satisfy the mechanical docking interface checkout requirement. No fluid servicing or activation is anticipated unless the radiators have been drained before air transportation. If this is the case, the external coolant loop must be filled.

If the gross status check is satisfactory, the flight modules will then proceed to a second mechanical docking interface test with an orbiter

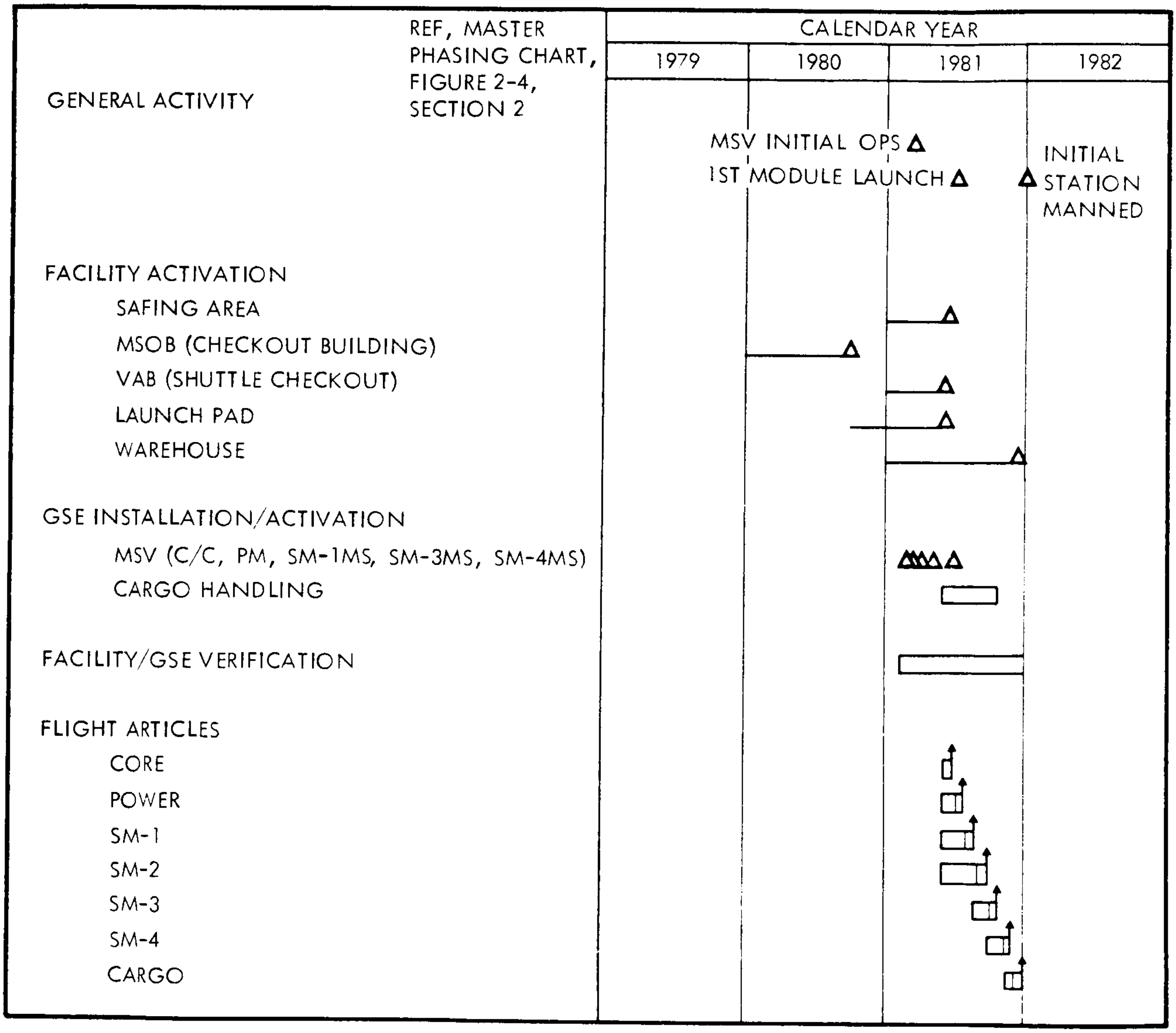


Figure 8-1. Prelaunch and Launch Operations Master Program Plan

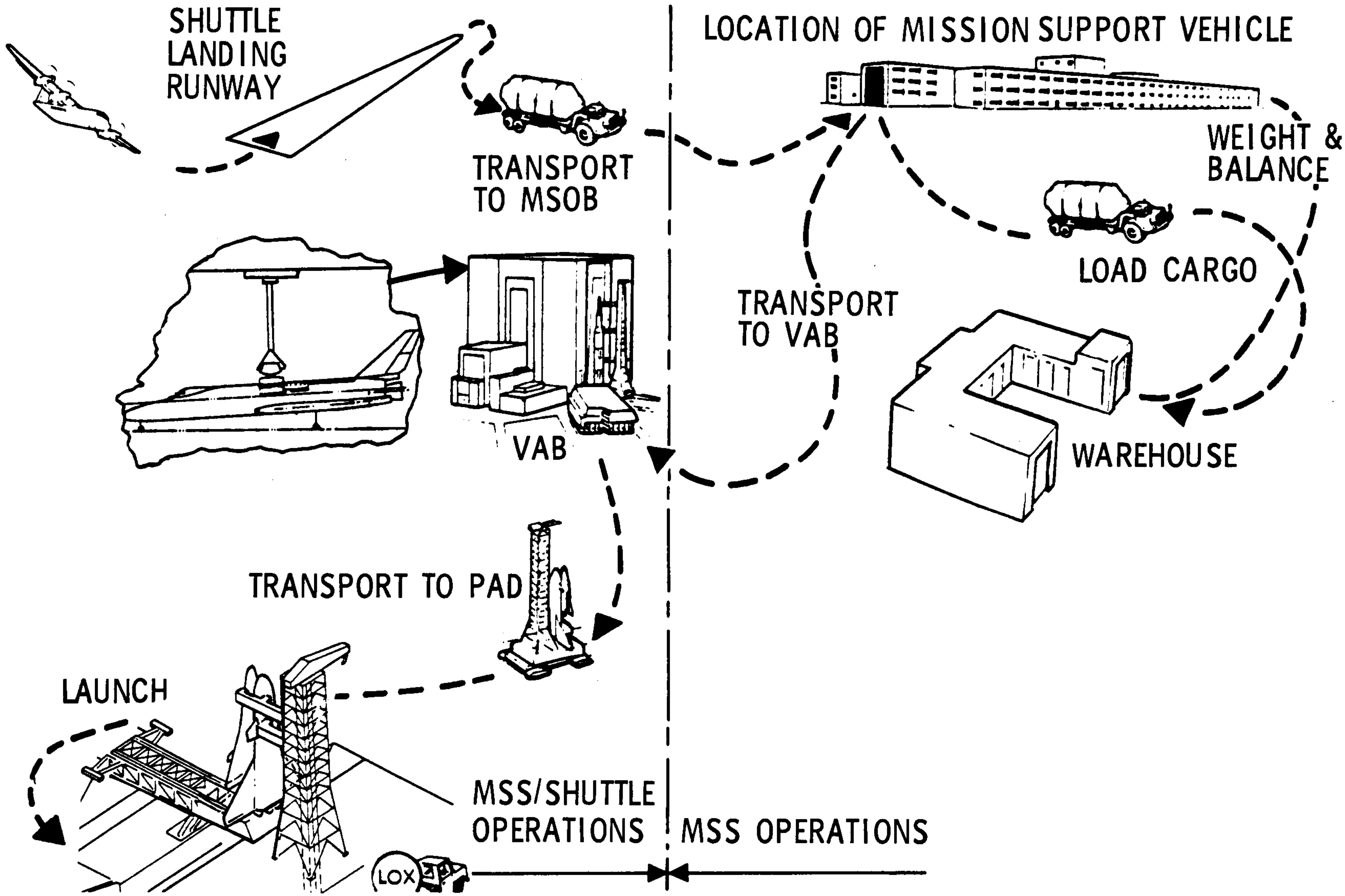


Figure 8-2. Typical MSS Module Flow at Launch Site

docking simulator. This simulator must be capable of simulating disconnect commands as well as the electrical power to actuate the unlocking mechanism.

8.2.2 MSOB FLIGHT MODULE ACCEPTANCE (SM-3, SM-4, CARGO GROWTH MODULES)

If the receiving inspection is satisfactory, the module will be docked to the MSV, hose and cable jumpers attached, and the module powered up in accordance with operating procedures (see Figure 8-3).

8.2.3 MODULE FUNCTIONAL CHECKOUT AND ORBITER INSTALLATION

The subsystems and sensor checkouts will be accomplished utilizing whatever MSV systems are required to be powered up for the particular test in progress. Figure 8-4 shows typical examples of functional checkout flow. Except for the cargo modules, which will be transferred to the cargo storage area for cargo loading, the modules will be transported directly to the shuttle maintenance and checkout facility for loading into the orbiter at approximately 20 hours before rollout to the pad. The loading will be accomplished in the vehicle assembly building.

8.2.4 ORBITER LOADING AT VAB

The modules will be hoisted above the orbiter and lowered into the cargo bay, maintaining an attitude compatible with that of the orbiter. After the module is fully lowered, the aft interface is established and the orbiter cargo retainer and centering device is engaged.

The crew in the orbiter cockpit will make all necessary checks of subsystem continuity and position indicators. After all checks have been made, the installation GSE is removed from the cargo bay and the bay doors closed. After installation operations have been completed, the access workstands will be removed and no further activity is planned until after the rollout is completed.

8.2.5 LAUNCH PAD OPERATIONS

The shuttle vehicle and LUT will be transferred to the launch pad by the crawler-transporter. At the launch pad, the LUT is secured to the pedestals, shuttle to ground service connections are made, and the MSS modules checked for preflight readiness.

When electrical power is available, status checks will be made in preparation for the mission readiness test. A final data review will be conducted after this test and completed before commencement of the launch countdown.

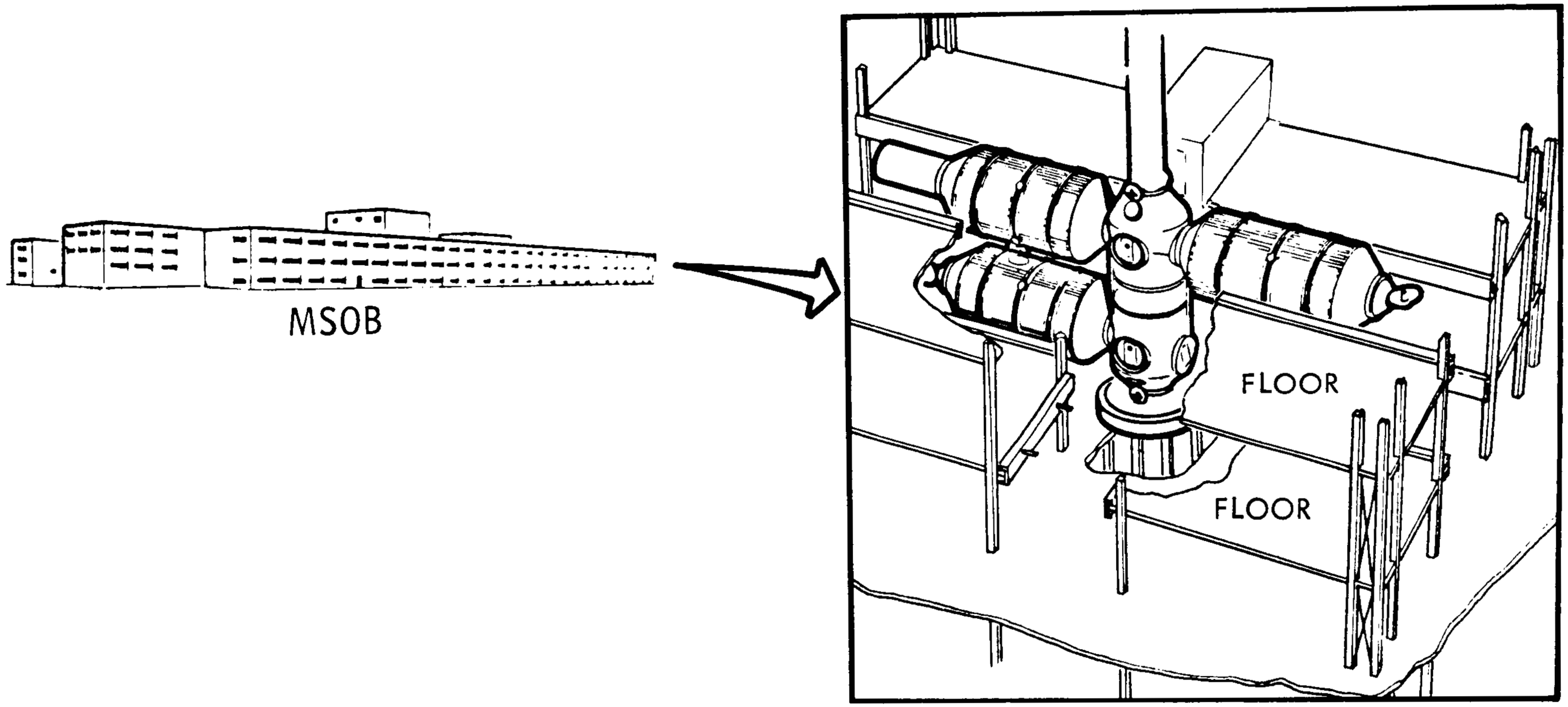


Figure 8-3. MSV MSOB Operations

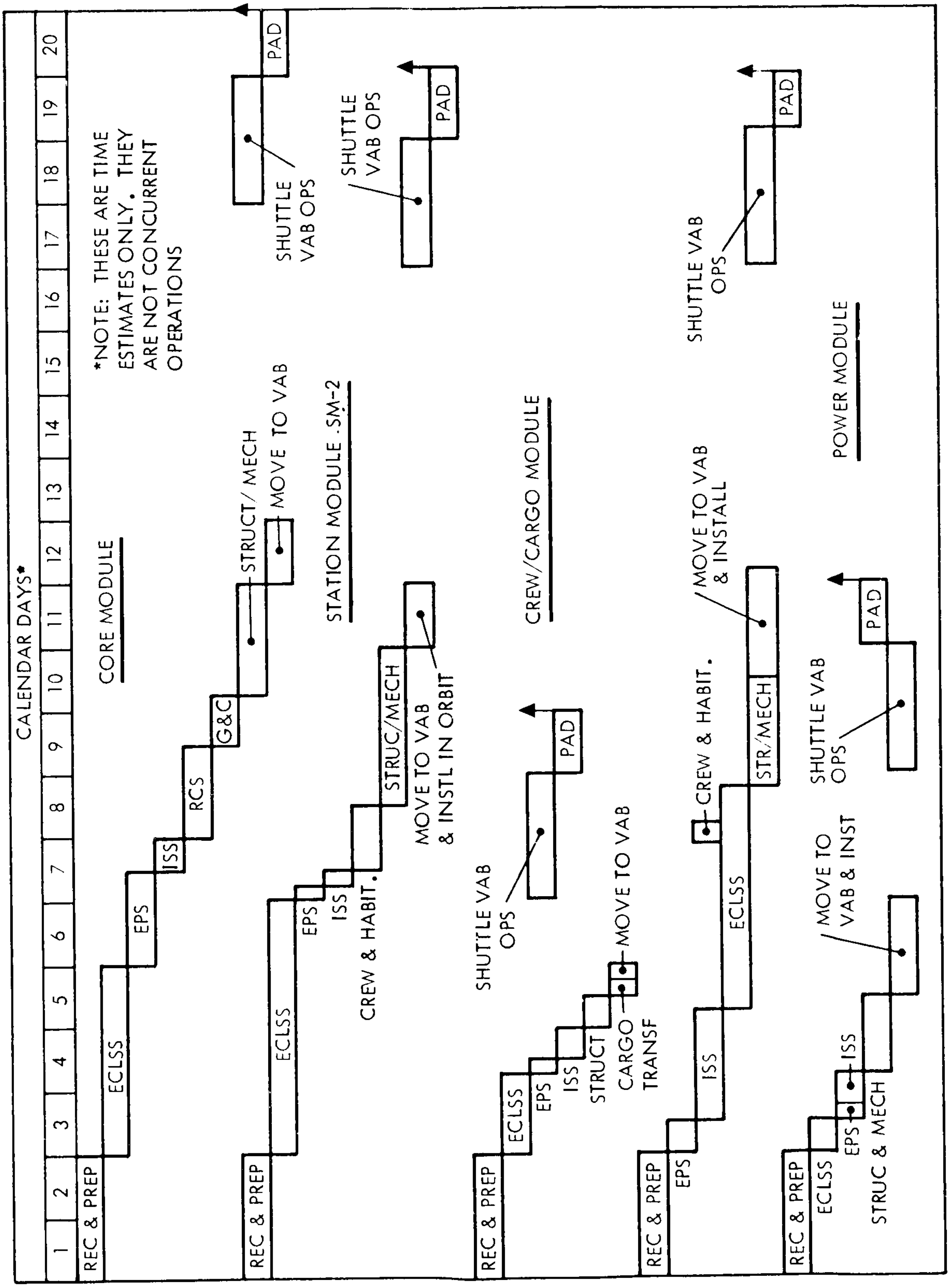


Figure 8-4. Functional Checkout Flow Diagram

Launch operations begin with the loading of cryogenic propellants (LO_2 and LH_2) into the shuttle booster and orbiter. After propellants are loaded, the flight personnel are transported to the launch site and board the vehicle. Propellants are replenished until the final stages of countdown operation. Final system activation and countdown operations are performed. Both airborne and ground systems are monitored for abort conditions that may occur anytime during launch operations. The launch countdown timeline is shown in Figure 8-5.

The launch pad area will be cleared of all personnel before loading propellants. Chilldown of transfer lines and shuttle tankage, venting, transfer of propellants, replenishment, and termination are accomplished by an automated system with contingency pause and refert capability. After chilldown, simultaneous loading of LO_2 and LH_2 into the booster, orbiter, and payload (if required) will being. The first phase of the loading after tank chilldown is a fine load (low rate of flow) followed by rapid load (high rate of flow). Completion of propellant loading is accomplished with another fine-load sequence.

Airborne level-sensing transducers, in conjunction with the ground computer system and ground transducers, will control the entire automated loading sequence. Remote control and display capability will be used throughout the countdown to monitor propellant loading operations.

The reactant storage tanks will be pressurized as soon as practical. As soon as single-phase conditions are achieved, the fuel cells will be started.

The launch pad facility will have a rapid-lift elevator within the service tower to transport four crew members, two loadmasters, ten passengers, and the closeout crew to the boarding platform access arms. The up passengers will generally be limited to six persons. The flight crews will board before the passengers and the closeout crew will ensure that each passenger and flight crew member is secured and ready for launch. The access arms will be moved to a standby position just clear of the booster and orbiter when the hatches are closed and the closeout crew has moved back to a safe area.

The launch vehicles and the launch pad service tower design will incorporate emergency egress capabilities for the flight crews, passengers, and other personnel during launch operations. This capability will be sustained as close to launch as possible. In addition, the launch facility will provide personnel safing areas to protect the crew, passengers, tower, and rescue team personnel from possible hazards.

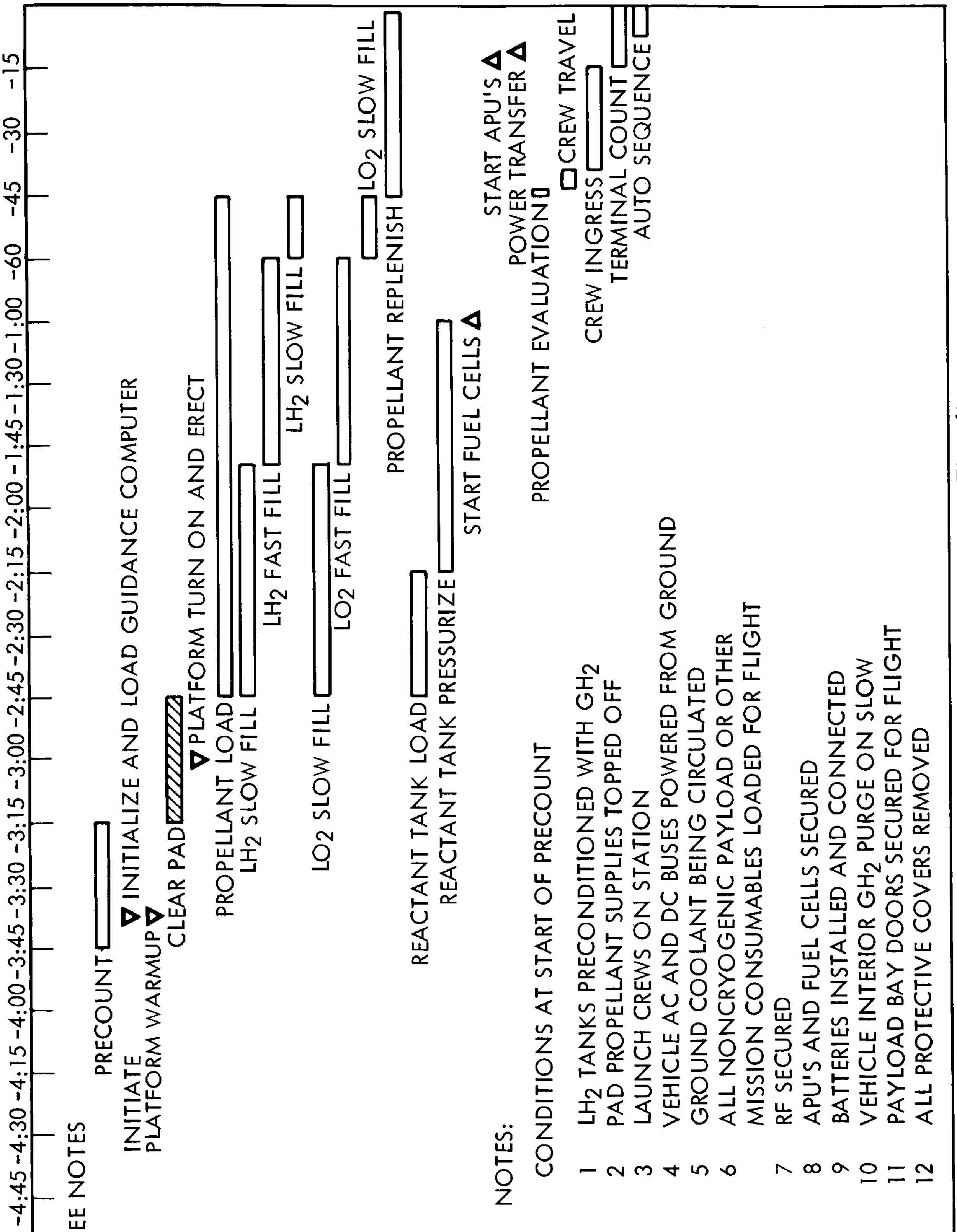


Figure 8-5. Shuttle Countdown Timeline

8.2.6 LAUNCH COUNTDOWN

With the completion of the crew boarding operations, the terminal countdown will be performed. The launch countdown checklist will be called up by the flight crews and displayed. Figure 8-5 depicts the shuttle countdown timeline used for the MSS study guideline.

Airborne systems will be scanned automatically for proper configuration and readiness for launch. The range safety officer will verify that the range is clear for launch. The mission director will determine that all mission criteria have been satisfied and will issue the clearance to launch. The crew will then verify that the ready-for-launch summary is present from all subsystems.

The launch program will be initiated by the flight crew. The launch sequence will progress automatically from this point to liftoff. During this sequence, the propellant replenishment will be terminated, the propellant tanks pressurized, the ground pneumatic system isolated, and the booster engines ignited. When an intermediate thrust level is reached, an evaluation of propulsion system performance will be made, a signal will be transmitted to release the vehicle stabilizing system, and the thrust level will be commanded to go to normal. When the thrust-to-weight ratio is greater than 1.0, the space shuttle achieves a free liftoff and rises from the launch pad, and simultaneously activates the liftoff signal.

8.2.7 RECOVERY AREA

Post-landing operations (recovery) include the functions of crew and passenger egress, cargo removal, and preparation for maintenance.

After landing and clearing the runway, the orbiter flight crew will initiate onboard safing procedures and shut down the subsystem. The orbiter will then be taxied or towed to the safing area for passenger and crew egress.

The orbiter will be safed and serviced in the safing area. This will include propellant detanking, purging, and venting. Preliminary visual inspections will be initiated during this time.

After the orbiter has been defueled, purged, safed, and the necessary preliminary inspection completed, the cargo bay doors will be closed and the vehicle towed to the maintenance and checkout facility at the modified VAB. After positioning in the maintenance bay, the work stands will be positioned, the cargo bay doors opened again, and the module removed with the facility crane. The module will then be transported to the MSOB or warehouse (in the case of the cargo module) by means of the module transporter.

8.2.8 MAINTENANCE AND REFURBISHMENT

Maintenance operations comprise the functions and activities from the conclusion of postlanding safing and servicing to prelaunch operations.

Scheduled maintenance will include those activities required for modification of basic structure and passenger equipment such as seats, EVA equipment, emergency equipment, food, water, waste management provisions, tools, and other mission-related equipment. Trend data will determine (from the evaluation of recorded flight data) the scheduled replacement of subsystem assemblies and components. Inspection performed during this activity may disclose requirements for unscheduled maintenance.

Major modifications may require recycling the modules to the MSV to verify interface compatibility or confirm revisions to station operating procedures.

Unscheduled maintenance will be largely controlled by recorded flight data and crew reports. Analysis of these data will be used to identify unscheduled maintenance activities, and when integrated with trend data, will provide a basis for changes in scheduled maintenance activities.

8.3 SHUTTLE INTERFACES

Shuttle facilities at KSC that have been identifed as common to the MSS program elements and the activities planned for those areas are discussed in this section.

8.3.1 VEHICLE ASSEMBLY BUILDING

Operations in this facility include loading into, or unloading modules from, the orbiter cargo bay. After the modules are loaded into the cargo bay, interface checks are accomplished. Integrated shuttle tests are supported after the orbiter and booster are mated with module systems monitored by the shuttle ISS.

These activities will require the use of overhead cranes, communications, access provisions, ground electrical power, and conditioned air for MSS utilization.

8.3.2 LAUNCH PAD

Operations at the launch pad include emergency egress and service arm tests for passengers, high-pressure gas loading, loading of passengers and time-critical cargo, and launch.

One service arm of the LUT must be suitable for use by the MSS for access and service utilities.

Equipment for loading the gases, venting the storage tanks, and for providing electrical power will be required. This equipment will include certain GSE and allocated command and control channels of the shuttle launch support equipment.

8.3.3 SAFING AREA

Upon return from space, the shuttle and payload require a safing area. For the MSS, this safing area will be used to off-load time-critical cargo and passengers from the CM, and high pressure gas storage tanks of other modules.

8.3.4 SHUTTLE INTERFACE REQUIREMENTS

Shuttle/space station interfaces have been subdivided into two categories for this study. One category consists of the interfaces for which there are no prelaunch operational influences. Examples of these interfaces are the information subsystem, safety monitoring, electrical power, environmental subsystem, and communications.

The design considerations ensure compatibility of these interfaces, which are verified during prelaunch operations; however, there are no specific prelaunch operational considerations which influence the design.

The other category of interfaces are those influenced by prelaunch operational considerations. Checkout provisions, access, serviceability, and maintainability are among the design considerations influenced by ground operational techniques.

The following paragraphs define the requirements that the modular space station, including the cargo module, will impose on the shuttle program. In addition to the requirements, rationale for those requirements is provided. (See SD 71-221, MSS Shuttle Interface Requirements, for details.)

Command and Control

Shuttle ground command and control functions must be allocated to the space station program element being launched. Valve control and response signals will be required for loading high-pressure gas.

Additionally, controls will be required for safing the module in the event the launch were deferred for any reason, or canceled for module exchange.

Vent and Purge Lines

Vent and purge lines from the resupply gas tank on the cargo module and from the storage bottles on the other space station program elements must be provided to the outboard structure of the orbiter for expulsion overboard, to provide an overboard dump of fluids and capability to purge the tanks while on the ground.

This requirement exists not only for an emergency, for safing the bottles, but also for normal ground servicing.

Umbilical Location for Ground Handling

Several options exist for the location of the ground umbilical connection to the MSS program element. The specific requirement is that there is an umbilical for ground servicing and that this umbilical disengage either by a flyaway disconnect or other remote disconnect capability.

An umbilical to the ground must be able to handle electrical power, instrumentation signals, oxygen, nitrogen, hydrogen, and ground cooling and environmental air.

The disconnect must provide the capability for offloading, purging, and venting gas bottles.

Interface Checkout Capability

The shuttle orbiter must have the capability to verify interface connections between itself and the module in the cargo bay for those items that do interface. These items are monitor and alarm, electrical power, communications, and information subsystem interfaces.

The interface connections require verification before launch to assure the shuttle flight crew satisfactory safety monitoring in the cargo bay.

Tie-Down Arrangement

The tie-down arrangement between the module and the rails in the orbiter cargo bay must be adjustable to provide placement of the module in relation to its weight and center-of-gravity location. Additionally, a variable length or various lengths of adapters will be required to interconnect the module with the orbiter crew compartment hatch. Interface connections must be integral to the adapter.

This requirement necessitates flexibility in the location of the module within the allowable limits of the orbiter. The adapter must extend the interface of the orbiter hatch to the berthing port of the MSS program element.

Personnel Ingress/Egress Provision

Access to the MSS program element while in the orbiter cargo bay must be provided.

Interface umbilicals must be connected, time-critical cargo must be loaded, passengers must board, and final prelaunch checks of monitor and alarm functions, communications, and environmental systems must be performed.

Emergency Egress Provision

Provisions must be made for emergency egress from a modular space station program element while in the cargo bay. These provisions must include horizontal and vertical orbiter attitudes.

Emergency egress provisions must be made for personnel safety while performing tasks inside the MSS program element while it is in the cargo bay.

Emergency egress requirements are most critical while at the launch pad because of the propellants and high-pressure gases that are loaded onboard the shuttle vehicle and the MSS module.

Shuttle Safing Area Egress Provision for Personnel and Time-Critical Cargo Offloading After Landing

The shuttle safing area must accommodate the egress of passengers as well as crew members. Access routes through the orbiter must permit offloading of time-critical cargo and personnel.